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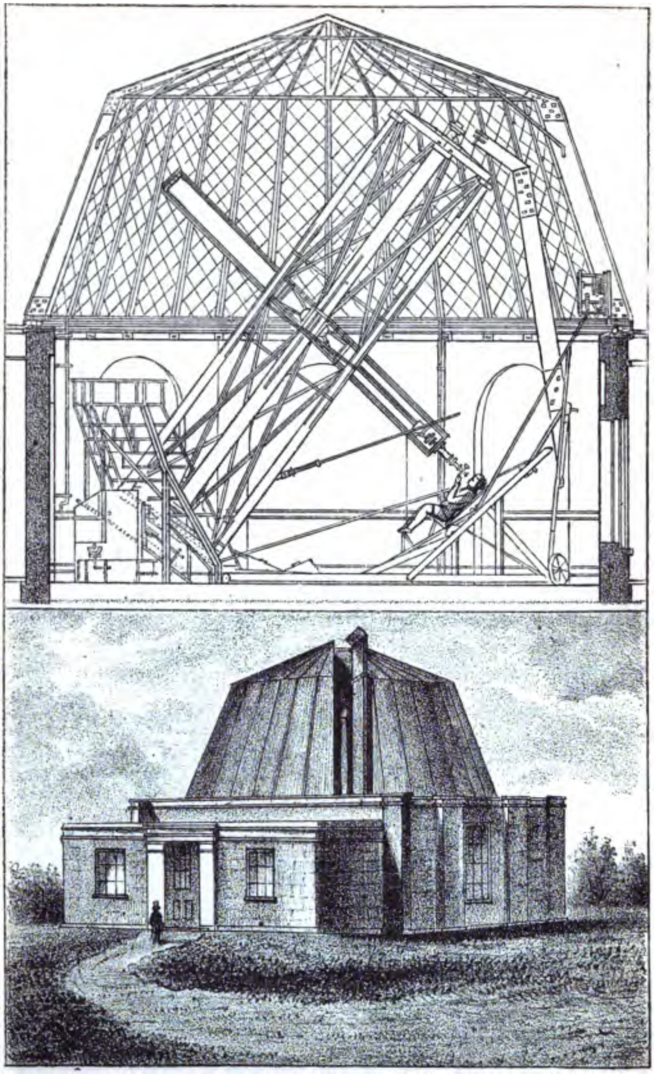

NORTHUMBERLAND TELESCOPE, CAMBRIDGE OBSERVATORY

POPULAR ASTRONOMY.

BY

DIONYSIUS LARDNER, D.C.L.,

Formerly Professor of Natural Philosophy and Astronomy in University College, London.

SECOND SERIES.

CONTAINING:

LIGHT.	ECLIPSES.
COMETS.	TERRESTRIAL ROTATION.
COMETARY INFLUENCES.	LUNAR ROTATION.

ASTRONOMICAL INSTRUMENTS.

FROM

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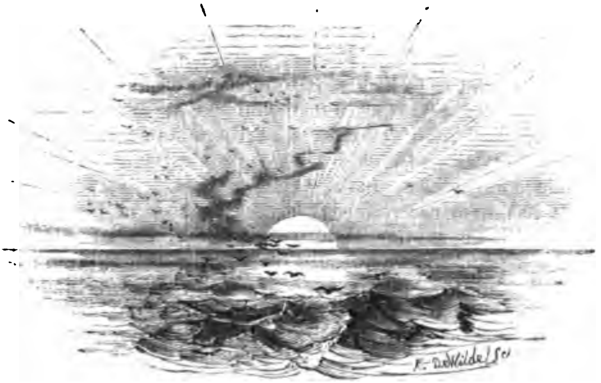


LIGHT.

1. Description of eye, and mode in which light is transmitted to it—Ways in which objects are rendered visible.—2. Analogy between the eye and the organ of smelling.—3. Analogy between the eye and the ear.—4. Luminiferous ether.—5. Corpuscular theory—Undulatory theory.—6. Undulatory theory explained and examined—Roemer's discovery of the velocity of light—Newton's solution of the amplitude or breadth of the luminous waves—Altitude of luminous waves—Table of the magnitudes of the luminous waves of each colour.—7. Consideration of the two theories of light.—8. The idea of the undulatory theory entertained by Descartes, Hooke, and others—The honour of having reduced the hypothesis to a definite shape attributable to Huygens—Dr. Young's mechanical reasoning thereon.—9. Malus discovers the polarisation of light by reflection—The theory greatly extended by Fresnel, Arago, Poisson, Herschel, and others.—10. Relation of light and heat—Herschel's discovery apparently establishing the independence of the heating and illuminating effects of the solar rays—Berard's experiments.—11. Bodies luminous and non-luminous.—12. Transparency and opacity.

1. Among the many marvellous results of the labours of the human mind directed to the discovery of the laws of the physical creation, there is perhaps none which strikes us with more astonishment than the knowledge which has been obtained relating to the qualities and laws of Light. I propose for the present to bring forward the facts which have been disclosed regarding its physical nature and its motion through space, as

well as the manner in which it affects the organ of vision, so as to produce the perception of external and distinct objects.

Between the eye and any distant object, there intervenes a space of greater or less extent, and often, as in the case of the stars, so great as to be incapable of being clearly and adequately expressed by any standard or modulus of magnitude with which we are familiar. Yet objects, at these immense distances, are rendered visible to us by some physical effects which they produce upon our organs of vision.

It has been ascertained that the interior of the eye-ball is lined with a membrane highly susceptible of mechanical vibration and connected by a continuity of nerves with the brain; and to this membrane admission is given to light by an opening in front of the eye called the *pupil.* The light then proceeding from any distant object must be supposed to pass over the space intervening between the object and the eye, to enter the pupil and to produce upon the membrane within the eye a specific mechanical effect, which being propagated to the brain, is the means of producing in the mind a perception of the distant object.

How then are we to conceive that an object placed at any distance, for example, say one hundred millions of miles, from the eye, can transmit over and through that space a mechanical effect on the eye? We answer that there are two, and only two, ways in which it is possible to conceive such an action to take place. These two are the following:—

First.—The distant object thus visible to us, may emit particles of matter from its surface, which particles of matter may pass over the intervening space, may enter the pupil of the eye, may strike upon the nervous membrane, and so affect it as to produce vision.

Secondly.—There may be in the space between the distant visible object and the eye, *a medium possessing elasticity,* so as to be capable of receiving and transmitting pulsations or undulations like those imparted to the air by a sounding body. If this be admitted, the distant visible object may, without emitting any particles of matter from its surface, affect such a medium surrounding it with pulsations or undulations, in the same manner as a bell affects the air around it. These pulsations or undulations may pass along the space intervening between the visible object and the eye, in the same manner as the pulsations or undulations produced by a bell pass along the air between the bell and the ear. In this manner, the pulsations transmitted from the visible object, and propagated by the medium we have referred to, may reach the eye and affect the membrane which lines it, in the same manner exactly as the pulsations in the air affect the tympanum of the ear.

These are the two, and the only two modes, in which it was ever imagined that a distant object could become visible to the eye.

2. In the first, there is an analogy between the eye and the organs of smelling. Odorous objects do actually emit material effluvia, which form part of their own substance. These effluvia reach the organ of smelling, and produce upon it a specific effect, which impresses the mind with a corresponding perception. According to the first supposition, a visible object at any distance would act in the same way, and would eject continual particles of light, which particles of light would move to the eye and produce vision, acting mechanically on its membrane in the same manner as the effluvia of a rose produce a sensible effect upon the organs of smelling.

3. The second method places the eye in analogy with the ear So close is this analogy, that all the mathematical formulæ by which the effects of sound are expressed in acoustics, will, with very slight changes, be capable of expressing the effects of vision, according to the latter hypothesis.

4. It is evident, however, that as the first hypothesis requires us to admit that distant visible objects are continually ejecting matter from their surfaces to produce vision; so the second hypothesis as peremptorily requires the admission of the existence of some physical medium pervading the universe,—some subtle ethereal fluid endowed with a property of propagating the pulsations or undulations of distant visible objects, and transmitting them to the eye. This hypothetical fluid has been called the *luminiferous ether.*

5. The first of these two celebrated theories of light has been called the CORPUSCULAR THEORY, and the second the UNDULATORY THEORY.

Newton, although he did not identify his investigations in optics with any hypothesis, but in the spirit of the inductive philosophy founded by Bacon based his conclusions on experiments and observations only, adopted nevertheless the nomenclature and language of the corpuscular theory, and, probably, from veneration for his authority, English philosophers, until recently, have very generally given the preference to that theory.

The undulatory theory, on the other hand, was adopted by Huygens, and after him by most continental philosophers.

Optical researches within the last hundred years have been prosecuted with singular diligence and success. A vast variety of phenomena previously unknown, have been accurately investigated, new laws have been developed, and the general result has been that the undulatory theory has prevailed over the corpuscular. It is perhaps not an unfair statement of the actual condition of these two celebrated hypotheses, to say that while the corpuscular system is found sufficient to explain most of the common and obvious phenomena of optics, it totally fails in explaining many of the most remarkable effects brought to light by modern observations and experiments. On the other hand, the undulatory theory in general offers a satisfactory explanation for all. This circumstance has very properly and legitimately enlisted under that hypothesis almost all the leading scientific men of the present day.

Although the principal facts which we shall have now to explain are in fact independent of either of these two hypotheses, and incontestably true, whichever may be adopted, yet in their exposition it will be necessary to adopt the language of one or the other of these theories. We shall, for the reason just stated, use the nomenclature of the undulatory theory.

We are then to imagine light to consist of undulations propagated through the universal ether, in the same manner as the waves or undulations of sound are propagated through the air.

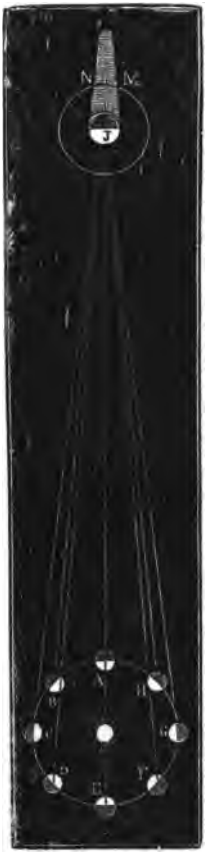
6. The first question then that arises is, what is the velocity with which these waves move? At what rate does light come from a distant star to the eye? Is it propagated instantaneously? Would a fire suddenly lighted at a point one hundred millions of miles from the eye be seen at the moment the light was produced?—or would an interval of time be necessary to allow the light to reach the eye? and if so, what would be the interval of time in relation to the distance of the luminous object?

In tracing the progress of human knowledge, we frequently have occasion to behold with surprise, and not without a due sense of humility, the important part which accident plays in the advancement of science. Often are we with diligent zeal in search of things, which, if found, would be of trifling or no value, when we stumble on inestimable treasures of truth. The frequency of this strongly impresses the mind with the persuasion that there is in secret operation a power whose will it is that knowledge and the human mind should be constantly progressive. It is in physics as in morals. We ignorantly seek that which is worthless, and find what is inestimable.

In the pursuit of knowledge we might well say that which we are taught to express in the pursuit of what is moral and good. We might say that the power which governs its progress knows better than we do "our necessities before we ask, and our ignorance in asking." We shall see a striking example of this in the narrative of the celebrated discovery of the motion of light.

Soon after the invention of the telescope, and the consequent discovery of Jupiter's satellites, Roemer an eminent Danish astronomer, engaged in a series of observations, the object of which was the discovery of the exact time of the revolution of one of these bodies around Jupiter. The mode in which he proposed to investigate this, was by observing the successive eclipses of the satellite, and noticing the time between them.

Fig. 1.



Let S (fig. 1) represent the sun, and A B C D E F G H the successive relative positions of the earth. Let J be Jupiter projecting behind him his conical shadow, and let M N represent the orbit of one of his satellites. After each revolution the satellite will enter the shadow at M, and emerge from it at N.

Now if it were possible to observe accurately the moment at which the satellite would, after each revolution, either enter the shadow or emerge from it, the interval of time between these events would enable us to calculate exactly the velocity and motion of the satellite. But by attentively watching the satellite we can note the time it enters the shadow, for at that moment it is deprived of the sun's light and becomes invisible. We can also note the moment of its emergence, because then escaping from the edge of the shadow, it comes into the sun's light and becomes visible. It was in this manner that Roemer proposed to ascertain the motion of the satellite. But in order to obtain the estimate with the greatest possible precision, he proposed to continue his observations for several months.

Let us, then, suppose that we have observed the time which has elapsed between two successive eclipses, and that this time is, for example, forty-three hours. We ought to expect that the eclipse would recur after the lapse of every successive period of forty-three hours.

Imagine a table to be computed in which we shall calculate and register beforehand the moment at which every successive eclipse of the satellite for twelve months to come shall occur, we shall then, as Roemer did, observe the moments at which the eclipses occur and compare them with the moments registered in the table.

Let the earth be supposed at A, at the commencement of these observations, where it is nearest to Jupiter. When the earth has moved to B, which it will do in about six weeks, it will be found that the occurrence of the eclipse is *a little later* than the time registered in the table. When the earth arrives at C, which it will do at the end of three months, it will occur *still later* than the registered time. In fact, at C the eclipses will occur about eight minutes later than the registered time. At D they will be twelve minutes later, and at E sixteen minutes later.

By observations such as these, Roemer was struck with the fact that his predictions of the eclipses proved in every case to be wrong. It would at first occur to him that this discrepancy might arise from some errors of his observations; but if such were the case, it might be expected that the result would betray that kind of irregularity which is always the character of such errors. Thus it would be expected that the predicted time would sometimes be later, and sometimes earlier than the observed time, and that it would be later and earlier to an irregular extent. On the contrary, it was observed during an interval of little more than six months which the earth took to move from A to E, that the observed time was continually later than the predicted time, and moreover, that the interval by which it was later continually and regularly increased. This was an effect too regular and consistent to be supposed to arise from the casual errors of observation; it must have its origin in some physical cause of a regular kind.

The attention of Roemer being thus attracted to the question, he determined to pursue the investigation by continuing to observe the eclipses for another half year. Time accordingly rolled on, and the earth transporting the astronomer with it, moved from E to F. On arriving at F, and comparing the observed with the predicted eclipse, it was found that the observed time was now only twelve minutes later than the predicted time. Soon after the expiration of the ninth month when the earth arrived at G, the observed time was found to be only eight minutes later; at H it was only four minutes later, and finally, when the earth returned to its first relative position with the planet, the observed time corresponded precisely with the predicted time.*

From this course of observation and inquiry it became apparent that the lateness of the eclipse depended altogether on the increased distance of the earth from Jupiter. The greater that distance, the later was the occurrence of the eclipse as apparent to the observers, and on calculating the change of distance, it was found that the delay of the eclipse was exactly proportional to the increase of the earth's distance from the place where the eclipse occurred. Thus when the earth was at E, the eclipse was observed 16 minutes, or about 960 seconds later than when the earth was at A. The diameter of the orbit of the earth, A E, measuring about 190 millions of miles, it appeared that that distance produced a delay of 960 seconds, which was at the rate of 198,000 miles per second. It appeared, then, that for every 198,000 miles that the earth's distance from Jupiter was in creased, the observation of the eclipse was delayed one second.

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* The exact interval is 398 days, the synodic period of Jupiter.

Such were the facts which presented themselves to Roemer How were they to be explained? It would be absurd to suppose that the actual occurrence of the eclipses was delayed by the increased distance of the earth from Jupiter. These phenomena depend only on the motion of the satellite and the position of Jupiter's shadow, and have nothing to do with, and can have no dependence on the position or motion of the earth, yet unquestionably the time they *appear* to occur to an observer upon the earth, has a dependence on the distance of the earth from Jupiter.

To solve this difficulty, the happy idea occurred to Roemer that the moment at which we see the extinction of the satellite by its entrance into the shadow is not, in any case, the very moment at which that event takes place, but sometime afterward, viz.: such an interval as is sufficient for the light which left the satellite just before its extinction to reach the eye. Viewing the matter thus, it will be apparent that the more distant the earth is from the satellite, the longer will be the interval between the extinction of the satellite and the arrival of the last portion of light which left it, at the earth; but the moment of the extinction of the satellite is that of the commencement of the eclipse, and the moment of the arrival of the light at the earth is the moment the commencement of the eclipse is observed.

Thus Roemer with the greatest felicity and success explained the discrepancy between the calculated and the observed times of the eclipses; but he saw that these circumstances placed a great discovery at his hand. In short, it was apparent that light is propagated through space with a certain definite speed, and that the circumstances we have just explained supply the means of measuring that velocity.

We have shown that the eclipse of the satellite is delayed one second more for every 198,000 miles that the earth's distance from Jupiter is increased, the reason of which obviously is, that light takes one second to move over that space; hence it is apparent that the velocity of light is at the rate, in round numbers, of 200,000 miles per second.

Such was the discovery which has conferred immortality upon the name of Roemer; a discovery to which, as we have shown, he was accidentally led when seeking to determine the velocity of one of the moons of Jupiter. The velocity of light thus determined would, in the corpuscular theory, be regarded as that with which the particles of light issuing from the surface of a visible object move through space. In the undulatory theory, however, which is more generally received, this velocity is that with which the waves are propagated through space, in the same sense as waves appear to move on the surface of water if a pebble be dropped in to form a centre round which they are propagated.

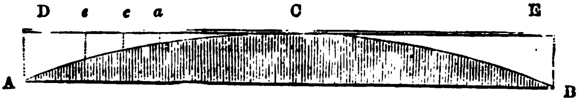
It is necessary to remember when considering any system of undulations, no matter through what medium they may be propagated, that the progressive motion which belongs to them is a motion of form merely, and not of matter. The waves which are propagated round a centre when a pebble is dropped into calm water, present an appearance to the eye as though the water which formed the wave really moved outward from the centre of the undulations. Such is, however, not the case. No particle of the fluid has any progressive motion whatever, of which many proofs may be offered. If any floating body be placed on the surface of the water, it will not be carried along by the waves, and if similar waves be formed, as they might be, by giving a peculiar motion to a sheet or cloth, they would have the same appearance of progressive motion, although the parts of the sheet or cloth, as is evident, would have no other motion than the up-and-down motion that would form the apparent undulations. The waves of the sea appear to the eye to be endowed with a progressive motion. A slight reflection, however, on the consequences of such a motion, will soon convince us that it can have no reality. The ship which floats upon the waves is not carried forward with them; they pass beneath her, now lifting her on their summits, and now letting her sink into the abyss between them. Observe a sea-fowl, or a nautilus floating on the water, and the same effect will be presented. If, however, the water itself partook of the motion as well as its waves, the ship and the fowl would be carried forward in the direction of that motion. Once on the summit of a wave, there they would continually remain, and their motion would be as smooth as if they were propelled on the calm surface of a lake.

We are then to remember that when light is propagated through space with the astonishing velocity of 200,000 miles per second, there is no material substance which really has this progressive velocity; it belongs merely to the form of the pulsations, or undulations. The same observations, exactly, are applicable to the transmission of the waves of sound through the air.

In order to submit the phenomena of light to a strict physical analysis, it is not enough to measure the motion of its waves. We require also to know their amplitude or breadth, just as, in the case of the waves of the sea, we should require to know not only the rate at which they are propagated over the surface of the water, but also the space which intervenes between the hollow or crest of each and the hollow or crest of the succeeding one.

For the solution of this problem we are indebted to Newton himself. To render intelligible the mode in which he solved it, let us imagine a flat plate of glass, such as D E (fig. 2), placed upon a convex lens of glass, the surface of which is represented by A B, but which must be supposed to have infinitely less curvature than that which appears in the figure.

Fig. 2.



The under surface of the flat plate will touch the vertex of the convexity at C, and the further any point on the under surface is from C, the greater will be the distance between the surfaces of the two glasses. Thus the distance between them at *a* is less than at *c*, and the distance at *c* is less than at *e*, and so on. The distance at the surfaces gradually increasing, in fact, from C outward.

If, looking down on the plate D E, we consider the point C as a centre, and a circle be described round it, at all points of that circle the surfaces of the glasses will have the same distances between them, and the greater that circle is, the greater will be the distance between the surfaces of glass.

Having the glasses thus arranged, Newton let a beam of light of some particular colour, produced by a prism, as red, for example, fall on the surface of the glass D E. He found that the effect produced was that a black spot appeared at the centre C, where the glasses touched; that immediately around this spot there appeared a circle of red light; that beyond that circle appeared a dark ring ; that outside of that dark ring there was another circle of red light, still having the point C as its centre. Outside this second circle appeared another dark ring, beyond which there was another circle of red light, and so on, a series of circles of red light, alternated with dark rings being formed, all having the point C as their common centre.

The distances between the surfaces of glass at which the successive circles of red light were found, were too minute to be directly measured, but they were easily calculated by measuring the diameters of the circles of light ; and, knowing the diameters of the convex surface A C B, this was a simple problem in geometry, easily solved, and admitting the greatest accuracy.

On making these calculations, Newton found that the distance between the glass surfaces where the second red circle was formed was double the distance corresponding to the first ; that at the third red circle the distance was triple that of the first, and so on. It followed, of course, that wherever the dark rings were formed, the distances between the glass surfaces were not an exact number of times the space corresponding to the first red circle.

Thus if we express the space between the glasses at the first red circle by 1, the space between them within that circle, toward the centre C, would be a fraction. The space corresponding to the first dark ring outside the first red circle, would be expressed by 1 and a fraction ; the space at the second red circle would be expressed by 2 ; the space at the second dark ring would be expressed by 2 and a fraction, and so on.

Newton was not slow to see that these phenomena were the direct manifestation of those effects which, in the corpuscular theory, whose nomenclature he used, corresponded to the amplitude of the waves of light in the undulatory theory. The space between the surfaces of glass at the first red ring was the amplitude of a single wave, the space at the second red circle the amplitude of two waves, and so on. Within the first red circle, the space between the glasses being less than the amplitude of a wave, the propagation of the undulation was stopped, and darkness ensued ; in like manner, in the space corresponding to the second dark ring, the distance between the glasses being greater than the amplitude of one wave, but less than the amplitude of two, the propagation was again stopped, and darkness produced. But at the second red circle, the space being equal to the amplitude of two waves, the undulations were reflected and the red ring produced, and so on.

It was evident, then, that to measure the amplitude of the luminous waves, it was only necessary to calculate the distance between the glasses at the first red ring.

When light of other colours was thrown upon the glass, a similar system of luminous rings was produced, but it was found in each case that the first ring varied in its diameter according to the colour of the light, and consequently that the amplitude of the waves of lights of different colours is different. It appeared that the waves of red light were the largest; orange came next to them; then yellow, green, blue, indigo, and violet, succeeded each other, the waves of each being less than those of the preceding. But the most astonishing part of this most celebrated investigation was the minuteness of these waves. It appeared that the waves of red light were so minute, that 40,000 of them would be comprised within an inch, while the waves of violet light, forming the other extreme of the series, were so small, that 60,000 spread over an inch, and the waves of light of other colours were of intermediate magnitudes.

Thus was discovered the physical cause of the splendour and variety of colours, and a singular and mysterious alliance was developed between colour and sound. Lights are of various hues, according to the magnitude of the pulsations that produce them, exactly as musical sounds vary their tone and pitch according to the magnitude of the aerial pulsations from which they result.

But this is not all. The alliance between sound and light does not terminate here. We have only spoken of the amplitude of the luminous waves, and have shown that it determines the tints of colours. What are we to say for the altitudes of the waves? Here, again, is another link of kindred between the eye and the ear. As the altitude of sonorous waves determines the loudness of the sounds, so the altitude of luminous waves determines the intensity or brightness of the colour.

There is one step more in the series of wondrous results which these memorable investigations have unfolded. As the perception of sound is produced by the tympanum of the ear vibrating in sympathetic accordance with the pulsations of the air produced by the sounding body, so the perception of light and colour is produced by similar pulsations of the membrane of the eye vibrating in accordance with ethereal pulsations propagated from the visible object. As in the case of the ear, the rigour of scientific investigation requires us to estimate the rate of the pulsation of the tympanum corresponding to each particular note, so in the case of light are we required to count the vibrations of the retina corresponding to every tint and colour. It may well be asked, in some spirit of incredulity, how the solution of such a problem could be hoped for; yet, as we shall now see, nothing can be more simple and obvious.

Let us suppose an object of any particular colour, a red star, for example, looked at from a distance. From the star to the eye there proceeds a continuous line of waves; these waves enter the pupil and impinge upon the retina; for each wave which thus strikes the retina, there will be a separate pulsation of that membrane. Its rate of pulsation, or the number of pulsations which it makes per second, will therefore be known, if we can ascertain how many luminous waves enter the eye per second.

It has been clearly shown that light moves at the rate of about 200,000 miles per second; it follows, therefore, that a length of ray amounting to 200,000 miles must enter the pupil each second; the number of times, therefore, per second, which the retina will vibrate, will be the same as the number of the luminous waves contained in a ray 200,000 miles long.

Let us take the case of red light. In 200,000 miles there are in round numbers 1000,000000 feet, and therefore 12000,000000 inches. In each of these 12000,000000 of inches there are 40000 waves of red light. In the whole length of the ray, therefore, there are 480,000000,000000 waves. Since this ray, however, enters the eye in one second, and the retina must pulsate once for each of these waves, we arrive at the astounding conclusion, that when we behold a red object, the membrane of the eye trembles at the rate of 480,000000,000000 of times between every two ticks of a common clock!

In the same manner, the rate of pulsation of the retina corresponding to other tints of colours is determined; and it is found that when violet light is perceived, it trembles at the rate of 720,000000,000000 of times per second.

In the annexed table are given the magnitudes of the luminous waves of each colour, the number of them which measure an inch, and the number of undulations per second which strike the eye:—

Colours.	Length of undulation in parts of an inch.	Number of undulations in an inch.	Number of undulations per second.
Extreme Red	0·0000266	37,640	458,000000,000000
Red	0·0000256	39,180	477,000000,000000
Orange	0·0000240	41,610	506,000000,000000
Yellow	0·0000227	44,000	535,000000,000000
Green	0·0000211	47,460	577,000000,000000
Blue	0·0000196	51,110	622,000000,000000
Indigo	0·0000185	54,070	658,000000,000000
Violet	0·0000174	57,490	699,000000,000000
Extreme Violet	0·0000167	59,750	727,000000,000000

The preceding calculations are, as will be easily perceived, made only in round numbers, with a view of rendering the principles of the investigation intelligible. In the table the exact results of the physical investigations which have been carried on, on this subject, are given.

7. Whichever theory we adopt to explain the phenomena of light we are led to conclusions that strike the mind with astonishment. According to the corpuscular theory, the molecules of light are supposed to be endowed with attractive and repulsive forces, to have poles to balance themselves about their centres of gravity, and to possess other physical properties which we can only ascribe to ponderable matter. In speaking of these properties, it is difficult to divest oneself of the idea of sensible magnitude, or by any strain of the imagination to conceive that particles to which they belong can be so amazingly small as those of light demonstrably are. If a molecule of light weighed a single grain, its momentum (by reason of the enormous velocity with which it moves) would be such that its effect would be equal to that of a cannon-ball of one hundred and fifty pounds, projected with a velocity of one thousand feet per second. How inconceivably small must they therefore be, when millions of molecules, collected by lenses or mirrors, have never been found to produce the slightest effect on the most delicate apparatus contrived expressly for the purpose of rendering their materiality sensible!

If the corpuscular theory astonishes us by the extreme minuteness and prodigious velocity of the luminous molecules, the numerical results deduced from the undulatory theory are not less overwhelming. The extreme smallness of the amplitude of the vibrations, and the almost inconceivable but still measurable rapidity with which they succeed each other, were computed by Dr. Young, and are exhibited in the above table.

8. That the sensation of light is produced by the vibrations of an extremely rare and subtle fluid, is an idea that was maintained by Descartes, Hooke, and some others; but it is to Huygens that the honour solely belongs of having reduced the hypothesis to a definite shape, and rendered it available to the purposes of mechanical explanation. Owing to the great success of Newton in applying the corpuscular theory to his splendid discoveries, the speculations of Huygens were long neglected; indeed, the theory remained in the same state in which it was left by him till it was taken up by our countryman, the late Dr. Young. By a train of mechanical reasoning, which in point of ingenuity has seldom been equalled, Dr. Young was conducted to some very remarkable numerical relations among some of the apparently most dissimilar phenomena of optics to the general laws of diffraction, and to the two principles of coloration of crystallised substances.

9. Malus, so late as 1810, made the important discovery of the polarisation of light by reflection, and successfully explained the phenomenon by the hypothesis of an undulatory propagation. The theory subsequently received a great extension from the ingenious labours of Fresnel; and the still more recent researches of Arago, Poisson, Herschel, Airy, and others, have conferred on it so great a degree of probability, that it may almost be regarded as ranking in the class of demonstrated truths. "It is a theory," says Herschel, "which, if not founded in nature, is certainly one of the happiest fictions that the genius of man has yet invented to group together natural phenomena, as well as the most fortunate in the support it has received from all classes of new phenomena, which at their discovery seemed in irreconcileable opposition to it. It is, in fact, in all its applications and details, one succession of *felicities*; inasmuch as that we may almost be induced to say, if it be not true, it deserves to be."

10. Light and heat are so intimately related to each other, that philosophers have doubted whether they are identical principles, or merely co-existent in the luminous rays. They possess numerous properties in common: being reflected, refracted, and polarised, according to the same laws, and even exhibit the same phenomena of interference. Most substances during combustion give out both light and heat; and all bodies, except the gases, when heated to a high temperature, become incandescent. Nevertheless, there are many circumstances in which they appear to differ.

A thin plate of transparent glass interposed between the face and a blazing fire intercepts no sensible portion of the light, but most sensibly diminishes the heat. Light and heat are therefore not intercepted alike by the same substances. Heat is also combined in different degrees with the different rays of the solar spectrum. A very remarkable discovery on this subject was made by Sir William Herschel, which would seem to establish the independence of the heating and illuminating effects of the solar rays. Having placed thermometers in the several prismatic colours of the solar spectrum, he found the heating power of the rays gradually increased from the violet (where it was least) to the extreme red, and that the maximum temperature existed some distance beyond the red, out of the visible part of the spectrum. The experiment was soon after repeated with great care by Berard, who confirmed Herschel's conclusions relative to the augmentation of the calorific power from the violet to the red, and even beyond the spectrum. This discovery of the inequality of the heating power of the different rays led to the inquiry whether the chemical action produced by light upon certain bodies was merely the effect of the heat accompanying it, or owing to some other cause. By a series of delicate experiments, Berard found that this action is not only independent of the heating power, but follows entirely a different law; its intensity being greater in the violet ray, where the heating power is the least, and least in the red ray, where the heating power is the greatest. We are thus led to the conclusion that the solar rays possess at least three distinct powers—those of heating, illuminating, and effecting chemical combinations and decompositions; and these powers are distributed among the different refrangible rays in such a manner as to show their complete independence of each other.

11. In relation to the production of light, bodies are considered as luminous and non-luminous.

Luminous bodies, or luminaries, are those which are original sources of light, such, for example, as the sun, the flame of a lamp or candle, metal rendered red-hot, the electric spark, lightning, and so forth.

Luminaries are necessarily always visible when present, provided the light they emit be strong enough to excite the eye.

Non-luminous bodies are those which themselves produce no light, but which may be rendered temporarily luminous when placed in the presence of luminous bodies. These cease, however, to be luminous, and therefore visible, the moment the luminary from which they borrow their light is removed. Thus the sun, placed in the midst of the planets, satellites, and comets, renders these bodies luminous and visible; but when any of them is removed from the solar influence by the interposition of any object not pervious by light, they cease to be visible, as is manifest in the case of lunar eclipses, when the globe of the earth is interposed between the sun and moon, and the latter object is therefore deprived of light. A candle or lamp placed in the room renders the walls, furniture, and surrounding objects temporarily luminous, and therefore visible; but if the candle be screened by any object not pervious to light, those parts of the room from which light is intercepted would become invisible, did they not receive some light from the other parts of the room still illuminated. If, however, the candle or lamp be completely covered, all the objects in the room become invisible.

12. In relation to the propagation of light, bodies are considered as transparent and opaque. Bodies through which light passes freely are called transparent, because the eye placed behind them will see such light through them. Bodies, on the contrary, which do not admit light to pass through them, are

called opaque ; and such bodies consequently render a luminary invisible if interposed between it and the eye.

Transparency and opacity exist in various bodies in different degrees. Glass, air, and water are examples of very transparent bodies. The metals, stone, earth, wood, &c. are examples of opaque bodies.

Correctly speaking, no body is perfectly transparent or perfectly opaque.

There is no substance, however transparent, which does not intercept some portion of light, however small. The light is thus intercepted in two ways ; first, when the light falls upon the surface of any body or medium, a portion of it is arrested, and either absorbed upon the surface, or reflected back from it ; the remainder passes through the body or medium, but in so passing more or less of it is absorbed, and this increases according to the extent of the medium through which the light passes. Analogy, therefore, justifies the conclusion that there is no transparent medium which, if sufficiently extensive, would not absorb all the light which passes into it.

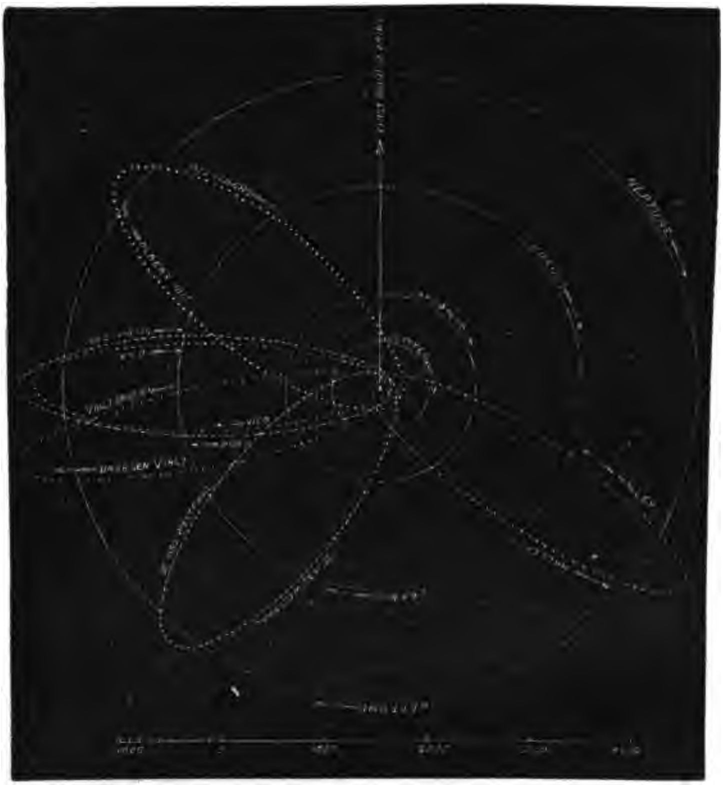


Fig. 5.

COMETS.

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CHAPTER I.

I. COMETARY ORBITS: 1. Prescience of the astronomer.—2. Strikingly illustrated by cometary discovery.—3. Motion of comets explained by gravitation.—4. Conditions imposed on the orbits of bodies which are subject to the attraction of gravitation.—5. Elliptic orbit.—6. Parabolic orbits.—7. Hyperbolic orbits.—8. Planets observe in their motions order not exacted by the law of gravitation.—9. Comets observe no such order in their motions.—10. They move in conic sections, with the sun for the focus.—11. Difficulty of ascertaining in what species of conic section a comet moves.—12. Hyperbolic and parabolic comets not periodic.—13. Elliptic comets periodic like the planets.—14. Difficulties attending the analysis of cometary motions. —15. Periodicity alone proves the elliptic character.—16. Periodicity combined with the identity of the paths while visible establishes identity.—17. Many comets recorded—few observed.—18. Classification of the cometary orbits.—II. ELLIPTIC COMETS REVOLVING WITHIN THE ORBIT OF SATURN: 19. Encké's comet.—20. Table of the elements of the orbit.—21. Indications of the effects of a resisting medium.—22. The luminiferous ether would produce such an effect.—23. Comets would ultimately fall into the sun.

I.—COMETARY ORBITS.

1. FOR the civil and political historian the past alone has existence—the present he rarely apprehends; the future never. To the historian of science it is permitted, however, to penetrate the depths of past and future with equal clearness and certainty: facts to come are to him as present, and not unfrequently more assured than facts which are passed. Although this clear perception of causes and consequences characterises the whole domain of physical science, and clothes the natural philosopher with powers denied to the political and moral inquirer, yet foreknowledge is eminently the privilege of the astronomer. Nature has raised the curtain of futurity, and displayed before him the succession of her decrees, so far as they affect the physical universe, for countless ages to come; and the revelations of which she has made him the instrument, are supported and verified by a never-ceasing train of predictions fulfilled. He "shows us the things which will be hereafter," not obscurely shadowed out in figures and in parables, as must necessarily be the case with other revelations, but attended with the most minute precision of time, place, and circumstance. He converts the hours as they roll into an ever-present miracle, in attestation of those laws which his Creator through him has unfolded; the sun cannot rise—the moon cannot wane—a star cannot twinkle in the firmament, without bearing witness to the truth of his prophetic records. It has pleased the "Lord and Governor" of the world, in his inscrutable wisdom, to baffle our inquiries into the nature and proximate cause of that wonderful faculty of intellect—that image of his own essence which he has conferred upon us; nay, the springs and wheelwork of animal and vegetable vitality are concealed from our view by an impenetrable veil, and the pride of philosophy is humbled by the spectacle of the physiologist bending in fruitless ardour over the dissection of the human brain, and peering in equally unproductive inquiry over the gambols of an animalcule. But how nobly is the darkness which envelopes metaphysical inquiries compensated by the flood of light which is shed upon the physical creation! *There* all is harmony, and order, and majesty, and beauty. From the chaos of social and political phenomena exhibited in human records—phenomena

unconnected to our imperfect vision by any discoverable law; a war of passions and prejudices, governed by no apparent purpose, tending to no apparent end, and setting all intelligible order at defiance—how soothing and yet how elevating it is to turn to the splendid spectacle which offers itself to the habitual contemplation of the astronomer! How favourable to the development of all the best and highest feelings of the soul are such objects! the only passion they inspire being the love of truth, and the chiefest pleasure of their votaries arising from excursions through the imposing scenery of the universe—scenery on a scale of grandeur and magnificence, compared with which whatever we are accustomed to call sublimity on our planet dwindles into ridiculous insignificancy. Most justly has it been said, that nature has implanted in our bosoms a craving after the discovery of truth, and assuredly that glorious instinct is never more irresistibly awakened than when our notice is directed to what is going on in the heavens. "Quoniam eadem Natura cupiditatem ingenuit hominibus veri inveniendi, quod facillime apparet, cum vacui curis, etiam quid in cœlo fiat, scire avemus; his initiis inducti omnia vera diligimus; id est, fidelia, simplicia, constantia; tum vana, falsa, fallentia odimus." *

2. Such reflections are awakened by every branch of astronomy, but by none so strongly as by the history of cometary discovery. No where can be found so marvellous a series of phenomena foretold. The interval between the prediction and its fulfilment has sometimes exceeded the limits of human life, and one generation has bequeathed its predictions to another, which has been filled with astonishment and admiration at witnessing their literal accomplishment.

3. In the vast framework of the theory of gravitation constructed by Newton, places were provided for the arrangement and exposition not only of all the astronomical phenomena which the observation of all preceding generations had supplied, but also for a far greater mass which the more fertile and active research of the generations which succeeded him have furnished. By this theory all the known planetary motions were explained, and planets previously unseen were felt by their effects, their places ascertained, and the telescope of the observer guided to them.

But transcendently the greatest triumph of this celebrated theory was the exposition it supplied of the physical laws which govern the motions of comets as distinguished from those which prevail among the planets.

4. It is proved in the propositions demonstrated in the first

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* Cic. de Fin. Bon. et Mal., ii. 14.

book of Newton's Principia, which propositions form in substance the ground-work of the entire theory of gravitation, that a body which is under the influence of a central force, the intensity of which decreases as the square of the distance increases, must move in one or other of the curves known to geometers as the "CONIC SECTIONS," being those which are formed by the intersection of the surface of a cone by a plane, and that the centre of attraction must be in the FOCUS of the curve; and in order to prove that such curves are compatible with no other law of attraction, it is further demonstrated that whenever a body is observed to move round a centre of attraction in any one of these curves, that centre being its focus, the law of the attraction will be that of gravitation; that is to say, its intensity will vary in the inverse proportion of the square of the distance of the moving body from the centre of force.

Subject to these limitations, however, a body may move round the sun in any orbit, at any distance, in any plane, and in any direction whatever. It may describe an ellipse of any eccentricity, from a perfect circle to the most elongated oval. This ellipse may be in any plane, from that of the ecliptic to one at right angles to it, and the body may move in such ellipses either in the same direction as the earth or in the contrary direction. Or the body thus subject to solar attraction may move in a parabola with its point of perihelion at any distance whatever from the sun, either grazing its very surface or sweeping beyond the orbit of Neptune, or, in fine, it may sweep round the sun in an hyperbola, entering and leaving the system in two divergent directions.

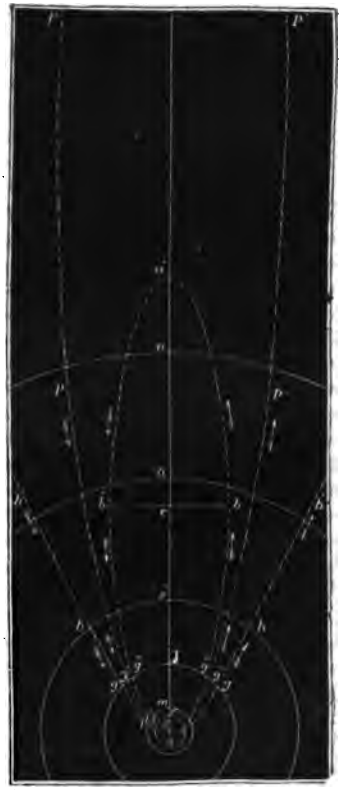
To render these explanations, which are of the greatest interest and importance in relation to the subject of comets, more clearly understood, we have represented, in fig. 1, the forms of a very eccentric ellipse, *a b a' b'*, a parabola *a p p'*, and an hyperbola *a h h'*, having *s* as their common focus, and it will be convenient to explain in the first instance the relative magnitude of some important lines and distances connected with these orbits.

5. Ellipses or ovals vary without limit in their eccentricity. A circle is regarded as an ellipse whose eccentricity is nothing. The orbits of the planets generally are ellipses, but having eccentricities so small that, if described on a large scale in their proper proportions on paper, they would be distinguishable from circles only by measuring accurately the dimensions taken in different directions, and thus ascertaining that they are longer in a certain direction than in another at right angles to it. A very eccentric and oblong ellipse is delineated in fig. 1, of which *a a'* is the major axis. The focus being *s*, the perihelion distance

d is *s a*, and the aphelion distance *d'* is *s a'*, the mean distance *a* being *s c*, or half the major axis.

The curvature of the ellipse continually increases from the mean distance to perihelion, and constantly decreases from perihelion to the mean distance, being equal at equal angular distances from perihelion as seen from the sun.

Fig. 1.



It is evident that if a body move in a very eccentric ellipse, such as that represented in fig. 1, whose plane coincides exactly or nearly with the common plane of the planetary orbits, it may intersect the orbits of several or all of the planets, as it is represented to do in the figure, although its mean distance from the sun may be less than the mean distance of several of those which it thus intersects. The aphelion distance of such a body may, therefore, greatly exceed that of any planet; while its mean distance may be less than that of the more distant planets.

6. The form of a parabolic orbit having the same perihelion distance as the elliptic orbit is represented at *a p p*, in fig. 1. This orbit consists of two indefinite branches, similar in form, which unite at perihelion *a*. Departing from this point on opposite sides of the axis *a a'*, their curvature regularly and rapidly decreases, being equal at equal distances from perihelion. The two branches have a constant tendency to assume the direction and form of two straight lines parallel to the axis *a a'*. To actual parallelism, and still less to convergence, these branches, however, never attain, and consequently they can never reunite. They extend, in fine, like parallel straight lines, to an unlimited

distance, without ever reuniting, but assuming directions which the distance from the focus bears a high ratio to the perihelion distance, which are practically undistinguishable from parallelism.

One parabolic orbit differs from another in its perihelion distance. The less this distance is, the less will be the separation at a given distance from *s* between the parallel directions to which the indefinite branches *p p′* tend. This distance may have any magnitude. The body in its perihelion may graze the surface of the sun, or may pass at a distance from it greater than that of the most remote of the planets, so that, although it be subject to solar attraction, it would in that case never enter within the limits of the solar system at all.

A body moving in such an orbit, therefore, would not make, like one which moves in an ellipse, a succession of revolutions round the sun; nor can the term periodic time be applied at all to its motion. It enters the system in some definite direction, such as *p′ p*, as indicated by the arrow from an indefinite distance. Arriving within the sensible influence of solar gravitation, the effects of this attraction are manifested in the curvation of its path, which gradually increases as its distance from the sun decreases, until it arrives at perihelion, where the attractive force, and consequently the curvature, attain their maxima. The extreme velocity which the body attains at this point produces, in virtue of the inertia of the moving mass, a centrifugal force, which counteracts the gravitation, and the body, after passing perihelion, begins to retreat; the solar gravitation and the curvature of its path decreasing together, until it issues from the system in a direction *p p′*, as indicated by the arrows, which is nearly a straight line, and parallel to that in which it entered. In such an orbit a body therefore visits the system but once. It enters in a certain direction from an indefinite distance, and, passing through its perihelion, issues in a parallel direction, passing to an unlimited distance, never to return.

7. Hyperbolic orbits, like the parabolas, consist of two indefinite branches, which unite at perihelion, which at equal distances from perihelion have equal curvatures, and which, as the distance from perihelion increases, approach indefinitely in direction and form to straight lines, but, unlike the parabolic orbits, the straight lines to whose direction the two branches approximate are divergent and not parallel.

Such an orbit having the same perihelion distance as the ellipse and parabola, is represented by *a h h′*, fig. 1.

The parabola is included between the ellipse and hyperbola.

8. When the theory of gravitation was first propounded by its

illustrious author, no other bodies, save the planets and satellites then discovered, were known to move under the influence of such a central attraction. These bodies, however, supplied no example of the play of that celebrated theory in its full latitude. They obeyed, it is true, its laws, but they did much more. They displayed a degree of harmony and order far exceeding what the law of gravitation exacted. Permitted by that law to move in any of the three classes of conic sections, their paths were exclusively elliptical; permitted to move in ellipses infinitely various in their eccentricities, they moved exclusively in such as differed almost insensibly from circles; permitted to move at distances subordinated to no regular law, they moved in a series of orbits at distances increasing in a regular progression; permitted to move at all conceivable angles with the plane of the ecliptic, their paths are inclined to it at angles limited in general to a few degrees; permitted, in fine, to move in either direction, they all agreed in moving in the direction in which the earth moves in its annual course.

Accordance so wondrous, and order so admirable, could not be fortuitous, and, not being enjoined by the conditions of the law of gravitation, must either be ascribed to the immediate dictates of the Omnipotent Architect of the universe above all general laws, or to some general laws superinduced upon gravitation, which had escaped the sagacity of the discoverer of that principle. If the former supposition were adopted, some bodies, different in their physical characters from the planets, primary and secondary, playing different parts and fulfilling different functions in the economy of the universe, might still be found, which would illustrate the play of gravitation in its full latitude, sweeping round the sun in all forms of orbit, eccentric, parabolic, and hyperbolic, in all planes, at all distances, and indifferently in both directions. If the latter supposition were accepted, then no other orbit, save ellipses of small eccentricity, with planes coinciding nearly with that of the ecliptic, would be physically possible.

9. The theory of gravitation had not long been promulgated, nor as yet been generally accepted, when the means of its further verification were sought in the motion of comets. Hitherto these bodies had been regarded as exceptional and abnormal, and as being exempt altogether from the operation of the law and order which prevailed in a manner so striking among the members of the solar system. So little attention had been given to comets that it had not been certainly ascertained whether they were to be classed as meteoric or cosmical phenomena; whether their theatre was the regions of the atmosphere, or the vast spaces in which the great bodies of the universe move. Their apparent positions in

the heavens on various occasions of the appearances of the most conspicuous of them had nevertheless been from time to time for some centuries observed and recorded with such a degree of precision as the existing state of astronomical science permitted; and even when their places were not astronomically ascertained, the date of their appearance was generally preserved in the historic records, and in many cases the constellations through which they passed were indicated, so that the means of obtaining at least a rude approximation to their position in the firmament were thus supplied.

10. Such observations, vague, scattered, and inexact as they were, supplied, however, data by which, in several cases, it was possible to compute the real motion of these bodies through space, their positions in relation to the sun, the earth, and the planets, and the paths they followed in moving through the system, with sufficiently approximate accuracy to conclude with certainty that they were one or other of the conic sections, the place of the sun being the focus.

This was sufficient to bring these bodies under the general operation of the attraction of gravitation.

It still remained, however, to determine more exactly the specific character of these orbits. Are they ellipses more or less eccentric? or parabolas? or hyperbolas?—Any of the three classes of orbits would, as has been shown, be equally compatible with the law of gravitation.

11. It might be supposed that the same course of observation as that by which the orbit of a planet is traced would be applicable equally to comets. Many circumstances, however, attend this latter class of bodies, which render such observations impossible, and compel the astronomer to resort to other means to determine their orbits.

A spectator stationed upon the earth keeps within his view each of the other planets of the system throughout nearly the whole of its course. Indeed, there is no part of the orbit of any planet in which, *at some time or other*, it may not be seen from the earth. Every point of the path of each planet can therefore be observed; and, although without waiting for such observation, its course might be determined, yet it is material here to attend to the fact, that the whole orbit may be submitted to direct observation. The different planets, also, present peculiar features by which each may be distinguished. Thus, as has been explained, they are observed to be spherical bodies of various magnitudes. Their surfaces are marked by peculiar modes of light and shade, which, although variable and shifting, still, in each case, possess some prevailing and permanent characters by which the identity of the object may be established, even were there no other means of determining it.

Unlike planets, comets do not present to us those individual characters above mentioned, by which their identity may be determined. None of them have been satisfactorily ascertained to be spherical bodies, nor indeed to have any definite shape. It is certain that many of them possess no solid matter, but are masses consisting of some nearly transparent substances; others are so surrounded with this apparently vaporous matter, that it is impossible, by any means of observation which we possess, to discover whether this vapour enshrouds within it any solid mass. The same vapour which thus envelopes the body (if such there be within it) also conceals from us its features and individual character. Even the limits of the vapour itself, if vapour it be, are subject to great change in each individual comet. Within a few days they are sometimes observed to increase or diminish some hundred-fold. A comet appearing at distant intervals presents, therefore, no very obvious means of recognition. A like extent of surrounding vapour would evidently be a fallible test of identity; and not less inconclusive would it be to infer diversity from a different extent of nebulosity.

If a comet, like a planet, revolved round the sun in an orbit nearly circular, it might be seen in every part of its path, and its identity might thus be established independently of any peculiar characters in its appearance. But such is not the course which comets are observed to take.

In general a comet is visible only throughout an arc of its orbit, which extends to a certain limited distance on each side of its perihelion. It first becomes apparent at some point of its path, such as g, g' or g'', fig. 1; it approaches the sun and disappears after it passes a corresponding point g, g' or g'' in departing from the sun. The arc of its orbit in which alone it is visible would therefore be $g\ a\ g$, $g'\ a\ g'$, or $g''\ a\ g''$.

If this arc, extending on either side of perihelion, could always be observed with the same precision as are the planetary orbits, it would be possible, by the properties of the conic sections, to determine not only the general character of the orbit, whether it be an ellipse, or parabola, or an hyperbola, but even to ascertain the individual curve of the one kind or the other in which the comet moves, so that the course it followed before it became visible, as well as that which it pursues after it ceases to be visible, would be as certainly and precisely known as if it could be traced by direct observation throughout its entire orbit.

12. If it be ascertained that the arc in which the comet moves while it is visible is part of an hyperbola, such as $g\ a\ g$, it will be

inferred that the comet coming from some indefinitely distant region of the universe, has entered the system in a certain direction, $h' h$, which can be inferred from the visible arc $g a g$, and that it must depart to another indefinitely distant region of the universe following the direction $h h'$, which is also ascertained from the visible arc $g a g$.

If, on the other hand, it be ascertained that the visible arc, such as $g' a g'$, be part of a parabola, then, in like manner by the properties of that curve, it will follow that it entered the system coming from an indefinitely distant region of the universe in a certain direction, $p' p$, which can be inferred from the visible arc $g' a g'$, and that after it ceases to be visible, it will issue from the system in another determinate direction, $p p'$, parallel to that by which it entered.

The comet, in neither of these cases, would have a periodic character. It would be analogous to one of those occasional meteors which are seen to shoot across the firmament never again to reappear. The body arriving from some distant region, and coming, as would appear, fortuitously within the solar attraction, is drawn from its course into the hyperbolic or parabolic path, which it is seen to pursue, and escapes from the solar attraction, issuing from the system never to return. The phenomenon would in each case be occasional, and, in a certain sense, accidental, and the body could not be said properly to belong to the system. So far as relates to the comet itself, the phenomenon would consist in a change of the direction of its course through the universe, operated by the temporary action of solar gravitation upon it.

13. But the case is very different, the tie between the comet and the system much more intimate, and the interest and physical importance of the body transcendently greater when the arc, such as $g'' a g''$, proves to be part of an ellipse. In that case, the invisible part of the orbit being inferred from the visible, the major axis $a a'$ would be known. The comet would possess the periodic character, making successive revolutions like the planets, and returning to perihelion a after the lapse of its proper periodic time, which could be inferred by the harmonic law from the magnitude of its major axis.

Such a body would then not be, like those which follow hyperbolic or parabolic paths, an occasional visit to the system, connected with it by no permanent relation, and subject to solar gravitation only accidentally and temporarily. It would, on the contrary, be as permanent, if not as strictly regular, a member of the system as any of the planets, though invested, as will presently appear, with an extremely different physical character.

It will therefore be easily conceived with what profound interest comets were regarded before the theory of gravitation had been yet firmly established or generally accepted, and while it was, so to speak, upon its trial. These bodies were, in fact, looked for as the witnesses whose testimony must decide its fate.

14. Difficulties, however, which seemed almost insurmountable, opposed themselves to a satisfactory and conclusive analysis of their motions. Many causes rendered the observations upon their apparent places few in number and deficient in precision. The arcs $g\ a\ g$, $g'\ a\ g'$, and $g''\ a\ g''$ of the three classes of orbit in any of which they might move without any violation of the law of gravitation were very nearly coincident in the neighbourhood of the place of perihelion a. It was, for example, in almost all the cases which presented themselves, possible to conceive three different curves, an eccentric ellipse, such as $a\ b\ a'\ b'$, a parabola, such as $p'\ p\ a$, and an hyperbola, such as $h'\ h\ a$, so related that the arcs $g\ a\ g$, $g'\ a\ g'$, and $g''\ a\ g''$, would not deviate one from another to an extent exceeding the errors inevitable in cometary observations. Thus any one of the three curves within the limits of the visible path of the comet might with equal fidelity represent its course. In such cases, therefore, it was impossible to infer, from the observations alone, whether the comet belonged to the class of hyperbolic or parabolic bodies, which have no periodic character, or to the elliptic, which has.

15. The character of periodicity itself, which belongs exclusively to elliptic orbits, supplied the means of surmounting this difficulty. If any observed comet have an elliptic motion, it must return to perihelion after completing its revolution, and it must have been visible on former returns to that position. Not only ought it to be expected, therefore, that such a comet would re-appear in future after absences of equal duration (depending on its periodic time), but that its previous returns to perihelion would be found by searching among the recorded appearances of such objects for any, the dates of whose appearance might correspond with the supposed period, and whose apparent motions, if observed, might indicate a real motion in an orbit, identical or nearly so with that of the comet in question.

If the motion of such a body were not affected by any other force except the solar attraction, it would re-appear after each successive revolution at exactly the same point; would follow, while visible, exactly the same arc $g''\ a\ g'$; would move in the same plane, inclined at the same angle to the ecliptic, the nodes retaining the same places; and would arrive at its perihelion at exactly the same point a, and after exactly equal intervals.

Now, although the disturbing actions of the planets near which it might pass, in departing from and returning to the sun, must be expected to be much more considerable than when one planet acts upon another, as well because of the extreme comparative lightness of the comet, as of the great eccentricity of its orbit, which sometimes actually or nearly intersects the paths of several planets, and especially those of the larger ones, yet still such planetary attractions are *only* disturbances, and cannot be supposed to efface that character which the orbit receives from the predominant force of the immense mass of the sun. While therefore we may be prepared for the possibility, and even the probability, that the same periodic comet on the occasion of its successive re-appearances, may follow a path $g' \, a \, g''$ in passing to and from its perihelion, differing to some extent from that which it had followed on previous appearances, yet in the main such differences cannot, except in rare and exceptional cases, be very considerable, and for the same reason the intervals between its successive periods, though they may differ, cannot be subject to any very great variation.

16. If then, on examining the various comets whose appearances have been recorded, and whose places while visible have been observed, and on computing from the apparent places the arc of the orbit through which they moved, it be found that two or more of them, while invisible, moved in the same path, the presumption will be that these were the same body re-appearing after having completed its motion in an elliptic orbit; nor should this presumption of identity be hastily rejected because of the existence of any discrepancies between the observed paths, or any inequality of the intervals between its successive re-appearances, so long as such discrepancies can fairly be ascribed to the possible disturbances produced by planets which the comet might have encountered in its path.

17. Many comets, however, have been *recorded*, but not *observed*. Historians have mentioned, and even described, their appearances, and in some cases have indicated the chief constellations through which such bodies passed, although no observations of their apparent places have been transmitted by which any close approximation to their actual paths could be made. Nevertheless, even in these cases, some clue to their identification is supplied. The intervals between their appearances alone is a highly probable test of identity. Thus if comets were regularly recorded to have appeared at intervals of fifty years (no circumstance affording evidence of the diversity of these objects), they might be assumed, with a high degree of probability, to be the successive returns of an elliptic comet having that interval as its period.

18. The appearances of about 400 comets had been recorded in the annals of various countries before the end of the seventeenth

century, the epoch signalised by the discoveries and researches of Newton. In most cases, however, the only circumstance recorded was the appearance of the object, accompanied in many instances with details bearing evident marks of exaggeration respecting its magnitude, form, and splendour. In some few cases, the constellations through which the object passed successively, with the necessary dates, are mentioned, and in some, fewer still, observations of a rough kind have been handed down. From such scanty data, eagerly sought for in the works preserved in different countries, sufficient materials have been collected for the computation, with more or less approximation, of the elements of the orbits of about sixty of the 400 comets above mentioned.

Since the time of Newton, Halley, and their contemporaries, observers have been more active, and have had the command of instruments of considerable and constantly increasing power; so that every comet which has been visible from the northern hemisphere of the earth since that time, has been observed with continually increasing precision, and data have been in all cases obtained, by which the elements of the orbits have been calculated. Since the year 1700, accordingly, about 140 have been observed, the elements of the orbits of which have been ascertained with great precision.

It appears, therefore, that of the entire number of comets which have appeared in the firmament, the orbits of about 200 have been ascertained. Of this number forty have been ascertained, some conclusively, others with more or less probability, to revolve in elliptic orbits.

Seven have passed through the system in hyperbolas, and consequently will not visit it again, unless they be thrown into other orbits by some disturbing force.

One hundred and sixty have passed through the system either in parabolic orbits, or in ellipses of such extreme eccentricity as to be undistinguishable from parabolas by any data supplied by the observations.

II.—ELLIPTIC COMETS REVOLVING WITHIN THE ORBIT OF SATURN.

19. In 1818, a comet was observed at Marseilles, on the 26th of November, by M. Pons. In the following January, its path being calculated, M. Arago immediately recognised it as identical with one which had appeared in 1805. Subsequently, M. Enckė of Berlin succeeded in calculating its entire orbit—inferring the invisible from the visible part—and found that its period was

about 1200 days. This calculation was verified by the fact of its return in 1822, since which time the comet has gone by the name of *Encké's comet*, and returned regularly.

It may be asked, How it could have happened that a comet which made its revolution in a period so short as three years and a quarter, should not have been observed until so recent an epoch as 1818? This is explained by the fact that the comet is so small, and its light so feeble even when in the most favourable position, that it can only be seen with the aid of the telescope, and not even with this except under certain conditions which are not fulfilled on the occasion of every perihelion passage. Nevertheless, the comet was observed on three former occasions, and the general elements of its path recorded, although its elliptic, and consequently periodic character, was not recognised.

On comparing, however, the elements then observed with those of the comet now ascertained, no doubt can be entertained of their identity.

20. In the following table are given the elements of the orbit of this comet, as computed from the observations made upon it at each of its three appearances in 1786, 1795, and 1805, before its periodic character was discovered, and at its eleven subsequent appearances up to 1852.

TABLE I.

Elements of the Orbit of Encké's Comet to 1852.

	Mean Distance, Earth's = 1.	Eccentricity.	Perihelion Distance.	Aphelion Distance.	Longitude of Perihelion.			Longitude of Ascending Node.			Inclination.			Time of Perihelion Passage.		
	a	e	$d'=a\times(1-e)$	$d''=a\times(1+e)$	ϖ			ν			i					
					°	′	″	°	′	″	°	′	″		h.	m.
1786	2·2080	0·8484	0·3348	4·0812	156	38	0	334	8	0	13	36	0	Jan. 30.	21	7
1795	2·2180	0·8489	0·3344	4·0916	156	41	20	334	39	22	13	42	30	Dec. 21.	10	44
1805	2·2131	0·8462	0·3404	4·0860	156	47	24	334	20	10	13	33	30	Nov. 21.	12	9
1819	2·2141	0·8486	0·3353	4·0929	156	59	12	334	33	19	13	36	54	Jan. 27.	6	18
1822	2·2244	0·8445	0·3460	4.1028	157	11	44	334	25	9	13	20	17	May 23.	23	16
1825	2·2233	0·8449	0·3449	4·1017	157	14	31	334	27	30	13	21	24	Sept. 16.	6	43
1829	2·2239	0·8446	0·3455	4·1023	157	17	53	334	29	32	13	20	34	Jan. 9.	18	3
1832	2 2219	0·8454	0·3435	4 1003	157	21	1	334	32	9	13	22	9	May 23.	23	34
1835	2·2227	0·8450	0·3444	4·1010	157	23	29	334	34	59	13	21	15	Aug. 26.	8	49
1838	2·2222	0 8452	0·3440	4·1004	157	27	4	334	36	41	13	21	28	Dec. 19.	0	27
1842	2·2229	0·8448	0·3450	4·0998	157	29	27	334	39	10	13	20	26	April 12.	0	35
1845	2·2215	0·8474	0.3381	4·1049	157	44	21	334	19	34	13	7	34	Aug. 9.	15	11
1848	2·2147	0·8478	0·3371	4 0923	157	47	8	334	22	12				Nov. 26.	3+	0
1852	2·2152	0·8477	0·3374	4·0930	157	51	2	334	23	21	13	7	55	March 14.	20	

M. T. B.

The motion of this comet is direct; and its period in 1852 was 3·29616 years, which is subject to a slight variation.

It is evident that between 1786 and 1795 there were two, between 1795 and 1805 two, and, in fine, between 1805 and 1819 three, unobserved returns to perihelion.

It appears, therefore, that, excepting the oval form of the orbit, the motion of this body differs in nothing from that of a planet whose mean distance from the sun is that of the nearest of the planetoids. Its eccentricity is such, however, that when in perihelion it is within the orbit of Mercury, and when in aphelion it is outside the most distant of the planetoids, and at a distance from the sun equal to four-fifths of that of Jupiter.

21. A fact altogether anomalous in the motions of the bodies of the solar system, and indicating a consequence of the highest physical importance, has been disclosed in the observation of the motion of this comet. It has been found that its periodic time, and consequently its mean distance, undergoes a slow, gradual, and apparently regular decrease. The decrease is small, but not at all uncertain. It amounted to about a day in ten revolutions, a quantity which could not by any means be placed to the account either of errors of observation or of calculation; and, besides, this increase is incessant, whereas errors would affect the result sometimes one way and sometimes the other. The period of the comet between 1786 and 1795 was $1208\frac{1}{9}$ days; between 1795 and 1805 it was $1207\frac{9}{10}$ days; between 1805 and 1819 it was $1207\frac{4}{10}$ days; in 1845 it was $1205\frac{1}{4}$ days; and, in fine, in 1852 it was 1204 days.

The magnitude of the orbit thus constantly decreasing (for the cube of its greater axis must decrease in the same proportion as the square of the period), the actual path followed by the comet must be a sort of elliptic spiral, the successive coils of which are very close together, every successive revolution bringing the comet nearer and nearer to the sun.

Such a motion could not arise from the disturbing action of the planets. These forces have been taken strictly into account in the computation of the ephemerides of the comet, and there is still found this residual phenomenon, which cannot be placed to their account, but which is exactly the effect which would arise from any physical agency by which the tangential motion of the comet would be feebly but constantly resisted. Such an agency, by diminishing the tangential velocity, would give increased efficacy to the solar attraction, and, consequently, increased curvature to the comet's path; so that, after each revolution, it would revolve at a less distance from the centre of attraction.

22. It is evident that a resisting medium, such as the luminiferous ether * is assumed to be in the hypothesis which forms

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* See "Hand-Book of Astronomy," § 1225.

the basis of the undulatory theory of light, would produce just such a phenomenon, and accordingly the motion of this comet is regarded as a strong evidence tending to convert that hypothetical fluid into a real physical agent.

It remains to be seen whether a like phenomenon will be developed in the motion of other periodic comets. The discovery of these bodies, and the observation of their motions, are as yet too recent to enable astronomers, notwithstanding their greatly multiplied number, to pronounce decisively upon it.

23. If the existence of this resisting medium should be established by its observed effects on comets in general, it will follow, that, after the lapse of a certain time (many ages, it is true, but still a definite interval), the comets will be successively absorbed by the sun, unless, as is not improbable, they should be previously vaporised by their near approach to the solar fires, and should thus be incorporated with his atmosphere.

In the efforts by which the human mind labours after truth, it is curious to observe how often that desired object is stumbled upon by accident, or arrived at by reasoning which is false. One of Newton's conjectures respecting comets was, that they are "the aliment by which suns are sustained;" and he therefore concluded that these bodies were in a state of progressive decline upon the suns, round which they respectively swept; and that into these suns they from time to time fell. This opinion appears to have been cherished by Newton to the latest hours of his life: he not only consigned it to his immortal writings, but, at the age of eighty-three, a conversation took place between him and his nephew on this subject, which has come down to us. "I cannot say," said Newton, "when the comet of 1680 will fall into the sun; possibly after five or six revolutions; but whenever that time shall arrive, the heat of the sun will be raised by it to such a point, that our globe will be burnt, and all the animals upon it will perish. The new stars observed by Hipparchus, Tycho, and Kepler, must have proceeded from such a cause, for it is impossible otherwise to explain their sudden splendour." His nephew then asked him, "Why, when he stated in his writings that comets would fall into the sun, did he not also state those vast fires they must produce, as he supposed they had done in the stars?"—"Because," replied the old man, "the conflagrations of the sun concern us a little more directly. I have said, however," added he, smiling, "enough to enable the world to collect my opinion."

Fig. 19.—Jan. 24, 1836.

Fig. 21.—Jan. 26, 1836.

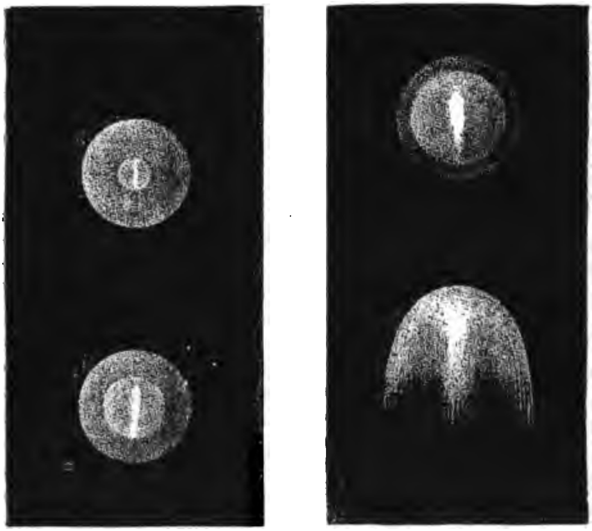

Fig. 20.—Jan. 25, 1836.

Fig. 22.—Jan. 27, 1836.

HALLEY'S COMET DEPARTING FROM THE SUN IN 1836.

COMETS.

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CHAPTER II.

24. Why like effects are not manifested in the motion of the planets.—25. Corrected estimate of the mass of Mercury.—26. Biela's comet.—27. Possibility of the collision of Biela's comet with the earth.—28. Resolution of Biela's comet into two.—29. Changes of appearance attending the separation.—30. Faye's comet.—31. Reappearance in 1850-1 calculated by M. Le Verrier.—32. De Vico's comet.—33. Brorsen's comet.—34. D'Arrest's comet.—35. Elliptic comet of 1743.—36. Elliptic comet of 1766.—37. Lexell's comet.—38. Analysis of Laplace applied to Lexell's comet.—39. Its orbit before 1767 and after 1770 calculated by his formulæ.—40. Revision of these researches by M. Le Verrier. —41. Process by which the identification of periodic comets may be decided.—42. Application of this process by M. Le Verrier to the comets of Faye, De Vico, and Brorsen, and that of Lexell—their diversity proved.—43. Probable identity of De Vico's comet with the

comet of 1678.—44. Blainplan's comet of 1819.—45. Pons's comet of 1819.—46. Pigott's comet of 1783.—47. Peters's comet of 1846.—48. Tabular synopsis of the orbits of the comets which revolve within Saturn's orbit.—49. Diagram of the orbits.—50. Planetary character of their orbits.—III. ELLIPTIC COMETS, WHOSE MEAN DISTANCES ARE NEARLY EQUAL TO THAT OF URANUS : 51. Comets of long periods first recognised as periodic.—52. Newton's conjectures as to the existence of comets of long periods.—53. Halley's researches.—54. Halley predicts its re-appearance in 1758-9.

24. IT may be asked, If the existence of a resisting medium be admitted, whether the same ultimate fate must not await the planets? To this inquiry it may be answered that, within the limits of past astronomical record, the ethereal medium, if it exist, has had no sensible effect on the motion of any planet. That it might have a perceptible effect upon comets, and yet not upon planets, will not be surprising, if the extreme lightness of the comets compared with their bulk be considered. The effect in the two cases may be compared to that of the atmosphere upon a piece of swan's down and upon a leaden bullet moving through it. It is certain that whatever may be the nature of this resisting medium, it will not, for many hundred years to come, produce the slightest perceptible effect upon the motions of the planets.

25. The masses of comets in general are, as will be explained, incomparably smaller than those of the smallest of the planets; so much so, indeed, as to bear no appreciable ratio to them. A consequence of this is, that while the effects of their attraction upon the planets are altogether insensible, the disturbing effects of the masses of the planets upon them are very considerable. These disturbances, being proportional to the disturbing masses, may then be used as measures of the latter, just as the movement of the pith-ball in the balance of torsion supplies a measure of the physical forces to which that instrument is applied.

Encké's comet, near its perihelion, passes near the orbit of Mercury; and when that planet, at the epoch of its perihelion, happens to be near the same point, a considerable and measurable disturbance is manifested in the comet's motion, which being observed, supplies a measure of the planet's mass.

This combination of the motions of the planet and comet took place under very favourable circumstances, on the occasion of the perihelion passage of the comet in 1838, the result of which, according to the calculations of Professor Encké, was the discovery of an error of large amount in the previous estimates of the mass of the planet. After making every allowance for other planetary attractions, and for the effects of the resisting medium, the existence of which it appears necessary to admit, it was inferred that the mass assigned to Mercury by Laplace was too great in the proportion of 12 to 7.

This question is still under examination, and every succeeding perihelion passage of the comet will increase the data by which its more exact solution may be accomplished.

26. On February 28, 1826, M. Biela, an Austrian officer, observed in Bohemia a comet, which was seen at Marseilles at about the same time by M. Gambart. The path which it pursued, was observed to be similar to that of comets which had appeared in 1772 and 1806. Finally, it was found that this body moved round the sun in an oval orbit, and that the time of its revolution was about 6 years and 8 months. It has since returned at its predicted times, and has been adopted as a member of our system, under the name of Biela's comet.

Biela's comet moves in an orbit whose plane is inclined at a small angle to those of the planets. It is but slightly oval, the length being to the breadth in the proportion of about 4 to 3. When nearest to the sun, its distance is a little less than that of the earth; and when most remote from the sun, its distance somewhat exceeds that of Jupiter. Thus it ranges through the solar system, between the orbits of Jupiter and the earth.

This comet had been observed in 1772 and in 1806; but the elliptic form of its orbit, and consequently its periodicity, was not discovered. Its return to perihelion was predicted and observed in 1832, in 1846, and in 1852; but that which took place in 1838 escaped observation, owing to its unfavourable position and extreme faintness.

A Table, showing the elements of this comet during each of its appearances from 1772 to 1846 inclusive, may be seen by reference to my "Hand-Book of Astronomy."

27. One of the points at which the orbit of Biela's comet intersects the plane of the ecliptic, is at a distance from the earth's orbit less than the sum of the semi-diameters of the earth and the comet. It follows, therefore (2905), that if the comet should arrive at this point at the same moment at which the earth passes through the point of its orbit which is nearest to it, a portion of the globe of the earth must penetrate the comet.

It was estimated on the occasion of the perihelion passage of this comet in 1832, that the semi-diameter of the comet (that body being nearly globular, and having no perceptible tail) was 21000 miles, while the distance of the point at which its centre passed through the plane of the ecliptic, on the 29th October in that year, from the path of the earth was only 18600 miles. If the centre of the earth happened to have been at the point of its orbit nearest to the centre of the comet on that day, the distance between the centres of the two bodies would have been only 18600 miles, while the semi-diameter of the comet was 21000 miles; and the semi-diameter of the earth being in round numbers 4000 miles, it would follow that in such a contingency the earth would have plunged into the comet to a depth of

$$21000 + 4000 - 18600 = 6400 \text{ miles},$$

a depth exceeding three-fourths of the earth's diameter.

The possibility of such a catastrophe having been rumoured, great popular alarm was excited before the expected return of the comet in 1832. It was, however, shown that on the 29th October the earth would be about five millions of miles from the point of danger, and that, on the arrival of the earth at that point, the comet would have moved to a still greater distance.

28. *Resolution of Biela's comet into two.*—One of the most extraordinary phenomena of which the history of astronomy affords any example, attended the appearance of this comet in 1846. It was on that occasion seen to resolve itself into two distinct comets, which, from the latter end of December, 1845, to the epoch of its disappearance in April, 1846, moved in distinct and independent orbits. The paths of these two bodies were in such optical juxtaposition that both were always seen together in the field of view of the telescope, and the greatest visual angle between their centres did not amount at any time to 10′, the variation of that angle arising principally from the change of direction of the visual line, relatively to the line joining their centres, and to the change of the comet's distance from the earth.

M. Plantamour, director of the Observatory of Geneva, calculated the orbits of these two comets, considered as independent bodies; and found that the real distance between their centres was, subject to but little variation while visible, about thirty-nine semi-diameters of the earth, or two-thirds of the moon's distance. The comets moved on thus side by side, without manifesting any reciprocal disturbing action; a circumstance no way surprising, considering the infinitely minute masses of such bodies.

29. The original comet was apparently a globular mass of nebulous matter, semi-transparent at its very centre, no appearance of a tail being discoverable. After the separation, both comets had short tails, parallel in their direction, and at right angles to the line joining their centres; both had nuclei. From the day of their separation the original comet decreased, and the companion increased, in brightness, until (on the 10th February) they were sensibly equal. After this the companion still increased

in brightness, and from the 14th to the 16th was not only greatly superior in brightness to the original, but had a sharp and star-like nucleus, compared to a diamond spark. The change of brightness was now reversed, the original comet recovering its superiority, and acquiring on the 18th the same appearance as the companion had from the 14th to the 16th. After this the companion gradually faded away, and disappeared previously to the final disappearance of the original comet on 22nd April.

It was observed also that a thin luminous line or arc was thrown across the space which separated the centres of the two nuclei, especially when one or the other had attained its greatest brightness, the arc appearing to emanate from that which for the moment was the brighter.

After the disappearance of the companion, the original comet threw out three faint tails, forming angles of 120° with each other, one of which was directed to the place which had been occupied by the companion.

It is suspected that the faint comet which was observed by Professor Secchi to precede Biela's comet in 1852, may have been the companion thus separated from it, and if so, the separation must be permanent, the distance between the parts being greater than that which separates the earth from the sun.

30. On the 22nd November, 1843, M. Faye, of the Paris Observatory, discovered a comet, the path of which soon appeared to be incompatible with the parabolic character. Dr. Goldschmidt showed that it moved in an ellipse of very limited dimensions, with a period of 7½ years. It was immediately observed as being extraordinary, that, notwithstanding the frequent returns to perihelion which such a period would infer, its previous appearances had not been recorded. M. Faye replied by showing that the aphelion of the orbit passed very near to the path of Jupiter, and that it was possible that the violent action of the great mass of that planet, in such close proximity with the comparatively light mass of the comet, might have thrown the latter body into its present orbit, its former path being either a parabola or an ellipse, with such elements as to prevent the comet from coming within visible distance. M. Faye supported these observations by reference to a more ancient comet, which we shall presently notice, to which a like incident is supposed with much probability, if not certainty, to have occurred.

31. The observations which had been made in 1843, at several observatories, but more especially those made by M. Struve at Pultowa, who continued to observe the comet long after it ceased to be observed elsewhere, supplied to M. Le Verrier the data necessary for the calculation of its motion in the interval between its

perihelion in 1843 and its expected re-appearance in 1850-1, subject to the disturbing action of the planets, and he predicted its succeeding perihelion for the 3rd of April, 1851.

Aided by the formulæ of M. Le Verrier, Lieutenant Stratford calculated a provisional ephemeris in 1850, by which observers might be enabled more easily to detect the comet, which was the more necessary as the object is extremely faint and small, and not capable of being seen except by means of the most perfect telescopes. By means of this ephemeris, Professor Challis, of Cambridge, found the comet on the night of the 28th November very nearly in the place assigned to it in the tables. Two observations only were then made upon it, which, however, were sufficient to enable M. Le Verrier to give still greater precision to his formulæ, by assigning a definite numerical value to a small quantity which before was left indeterminate. Lieutenant Stratford, with the formula thus corrected, calculated a more extensive and exact ephemeris, extending to the last day of March, and published it in January, 1851, in the Nautical Almanack.

The comet, though extremely faint and small, and consequently difficult of observation, continued to be observed by Professor Challis, with the great Northumberland telescope, at Cambridge, and by M. Struve at Pultowa, and it was found to move in exact accordance with the predictions.

32. On the 22nd August, 1844, M. de Vico, of the Roman Observatory, discovered a comet whose orbit was soon afterwards proved by M. Faye to be an ellipse of moderate eccentricity, with a period of about 5½ years. It arrived at its perihelion on the 2nd of September, and continued to be observed until the 7th of December.

33. On the 26th of February, 1846, M. Brorsen, of Kiel, discovered a faint comet, which was soon found to move in an elliptic orbit, with a period of about 5½ years. Its position in the heavens not being favourable, the observations upon it were few, and the resulting elements, consequently, not ascertained with all the precision that might be desired. Its re-appearance on its approach to the succeeding perihelion, was expected from September to November, 1851. It escaped observation, however, owing to its unfavourable position in relation to the sun. Its next perihelion passage will take place in 1857.

34. On the 27th of June, 1851, Dr. d'Arrest, of the Leipsic Observatory, discovered a faint comet, which M. Villarceaux proved to move in an elliptic orbit, with a period of about 6½ years. The next perihelion passage of this comet will take place in the end of 1857, or the beginning of 1858.

35. A revision of the recorded observations of former comets by

the more active and intelligent zeal of modern mathematicians and computers, has led to the discovery of the great probability of several among them having revolved in elliptic orbits, with periods not differing considerably from those of the comets above mentioned. The fact that these comets have not been re-observed on their successive returns through perihelion, may be explained, either by the difficulty of observing them, owing to their unfavourable positions, and the circumstance of observers not expecting their re-appearance, their periodic character not being then suspected; or because they may have been thrown by the disturbing action of the larger planets into orbits such as to keep them continually out of the range of view of terrestrial observers.

Among those may be mentioned a comet which appeared in 1743, and was observed by Zanetti at Bologna; the observations indicate an elliptic orbit, with a period of about 5½ years.

36. This comet, which was observed by Messier, at Paris, and by La Nux, at the Isle of Bourbon, revolved, according to the calculations of Burckhardt, in an ellipse with a period of 5 years.

37. The history of astronomy has recorded one singular example of a comet which appeared in the system, made two revolutions round the sun in an elliptic orbit, and then disappeared, never having been seen either before or since.

This comet was discovered by Messier, in June 1770, in the constellation of Sagittarius, between the head and the northern extremity of the bow, and was observed during that month. It disappeared in July, being lost in the sun's rays. After passing through its perihelion, it re-appeared about the 4th of August, and continued to be observed until the first days of October, when it finally disappeared.

All the attempts of the astronomers of that day failed to deduce the path of this comet from the observations, until six years later, in 1776, Lexell showed that the observations were explained, not, as had been assumed previously, by a parabolic path, but by an ellipse, and one, moreover, without any example at that epoch, which indicated the short period of 5½ years.

It was immediately objected to such a solution, that its admission would involve the consequence that the comet, with a period so short, and a magnitude and splendour such as it exhibited in 1770, must have been frequently seen on former returns to perihelion; whereas no record of any such appearance was found.

To this Lexell replied, by showing that the elements of its orbit, derived from the observations made in 1770, were such, that at its previous aphelion, in 1767, the comet must have passed within a distance of the planet Jupiter fifty-eight times less than its distance from the sun; and that consequently it must then have sustained an attraction from the great mass of that planet, more than three times more energetic than that of the sun; that consequently it was thrown out of the orbit in which it previously moved, into the elliptic orbit in which it actually moved in 1770; that its orbit previously to 1767 was, according to all probability, a parabola; and, in fine, that consequently moving in an elliptic orbit from 1767 to 1770, and having the periodicity consequent on such motion, it nevertheless moved only for the first time in its new orbit, and had never come within the sphere of the sun's attraction before this epoch.

Lexell further stated, that since the comet passed through its aphelion, which nearly intersected Jupiter's orbit, at intervals of somewhat above 5½ years, and it encountered the planet near that point in 1767, the period of the planet being somewhat above eleven years, the planet after a single revolution, and the comet after two revolutions, must necessarily again encounter each other in 1779; and, that since the orbit was such that the comet must in 1779 pass at a distance from Jupiter 500 times less than its distance from the sun, it must suffer from that planet an action 250 times greater than the sun's attraction, and that therefore it would in all probability be again thrown into a parabolic or hyperbolic path; and if so, that it would depart for ever from our system to visit other spheres of attraction. Lexell, therefore, anticipated the final disappearance of the comet, which actually took place.

In the interval between 1770 and 1779, the comet returned once to perihelion; but its position was such that it was above the horizon only during the day, and could not in the actual state of science be observed.

38. At this epoch analytical science had not yet supplied a definite solution of the problem of cometary disturbances. At a later period the question was resumed by Laplace who, in his celebrated work, the "Mécanique céleste," gave the general solution of the following problem:—

"The actual orbit of a comet being given, what was its orbit before, and what will be its orbit after being submitted to any given disturbing action of a planet near which it passes?"

39. Applying this to the particular case of Lexell's comet, and assuming as data the observations recorded in 1770, Laplace showed that, before sustaining the disturbing action of Jupiter in 1767, the comet must have moved in an ellipse of which the semi-axis major was 13·293, and consequently that its period, instead of being 5½ years, must have been 48½ years; and that the eccentricity of the orbit was such that its perihelion distance would be but very little less than the mean distance of Jupiter,

and that consequently it could never have been visible. It followed also that, after suffering the disturbing action of Jupiter in 1779, the comet passed into an elliptic orbit whose semi-axis major was 7·3, that its period was consequently twenty years, and that its eccentricity was such that its perihelion distance was more than twice the distance of Mars, and that in such an orbit it could not become visible.

40. This investigation was afterwards revised by M. Le Verrier,* which showed that the observations of 1770 were not sufficiently definite and accurate to justify conclusions so absolute. He has shown that the orbit of 1770 is subject to an uncertainty comprised between certain definite limits; that tracing the consequences of this to the positions of the comet in 1767 and 1779, these positions are subject to still wider limits of uncertainty. Thus he shows that, compatibly with the observations of 1770, the comet might in 1779 pass either considerably outside, or considerably inside Jupiter's orbit, or might, as it was supposed to have done, have passed actually within the orbits of his satellites. He deduces in fine the following general conclusions:—

1. That if the comet had passed within the orbits of the satellites, it must have fallen down upon the planet and coalesced with it; an incident which he thinks highly improbable, though not absolutely impossible.

2. The action of Jupiter may have thrown the comet into a parabolic or hyperbolic orbit, in which case it must have departed from our system altogether, never to return, except by the consequence of some disturbance produced in another sphere of attraction.

3. It may have been thrown into an elliptic orbit, having a great axis and long period, and so placed and formed that the comet could never become visible; a supposition within which comes the solution of Laplace.

4. It may have had merely its elliptic elements more or less modified by the action of the planet, without losing its character of short periodicity; a result which M. Le Verrier thinks the most probable, and which would render it possible that this comet may still be identified with some one of the many comets of short period, which the activity and sagacity of observers are every year discovering.

To facilitate such researches, M. Le Verrier has given a Table, including all the possible systems of elliptic elements of short period which the comet could have assumed, subject to the disturbing action of Jupiter in 1779, and taking the observations of 1770 within their possible limits of error.

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* See Mém. Acad. des Sciences, 1847, 1848.

He further demonstrates, that the orbit in which the comet moved antecedently to the disturbing action of Jupiter upon it in 1767, not only could not have been a parabola or hyperbola, but must have been an ellipse, whose major axis was considerably less than that which Laplace deduced from the insufficient observations of Messier. He shows that, before that epoch, the perihelion distance of the comet could not, under any possible supposition, have exceeded three times the earth's mean distance, and most probably was included between 1½ and 2 times that distance; and that the semi-axis major of the orbit could not have exceeded 4½ times the earth's mean distance, a magnitude 3 times less than that assigned to it by the calculations of Laplace.

41. It must not, however, be supposed that it is sufficient to compare the actual elements of each periodic comet thus discovered, with the elements given in the table of M. Le Verrier, and to infer the absence of identity from their discordance. Such an inference would only be rendered valid by showing, that in past ages, the comet in question had suffered no serious disturbing action by which the elements of its orbit could be considerably changed. To decide the question a much more laborious and difficult process must be encountered: a process from which the untiring spirit of M. Le Verrier has not shrunk. It is necessary, in fine, to the satisfactory and conclusive solution of such a problem, that the periodic comet in question should be traced back through all its previous revolutions up to 1779, that all the disturbances which it suffered from the planets which it encountered in that interval be calculated and ascertained, and that by such means the orbit which it must have had previous to such disturbances, in 1779, be determined. Such orbit would then be compared with the table of possible orbits of Lexell's comet, as given by M. Le Verrier; and if it were found to be identical with any of them, the identity of the comet in question with that of Lexell, would be inferred with the highest degree of probability; but if, on the other hand, such discrepancies were found to prevail as must exceed all supposable errors of observation or calculation, the diversity of the comets would follow.

42. M. Le Verrier has applied these principles to the comets of Faye, De Vico, and Brorsen; tracing back their histories during their unseen motions for three-quarters of a century, and ascertaining the effects of the disturbing actions which they must severally have sustained from revolution to revolution, until he

brought them to the epoch of 1779. On comparing the orbits thus determined with those of the table of possible orbits of Lexell's comet, he has shown that none of them can be identical with it, however strongly some of the elements of their present orbits may raise such a presumption.

43. The comet of De Vico having presented striking analogies with a comet which was observed by Tycho Brahe and Rothmann in 1585, and one observed by La Hire in 1678, M. Le Verrier has applied like principles to the investigation of these questions.

MM. Laugier and Mauvais observed that the elements of De Vico's comet presented such a resemblance to that of Tycho Brahe, as almost to decide the question of their identity. M. Le Verrier tracing back the comet of De Vico to 1585, has shown that its orbit at that epoch was so different from that of the comet of Tycho, as to be incompatible with any plausible inference of their identity.*

He has shown, however, by like reasoning, that there is a high degree of probability that the comet of De Vico is identical with that observed by La Hire in 1678.

44. M. Blainplan discovered a comet at Marseilles on the 28th November, 1819, which was observed at Milan until 25th January, 1820. The observations reduced and calculated by Prof. Encké gave an elliptic orbit with a period a little short of five years. Clausen conjectures that this comet may be identical with that of 1743. It has not been seen since 1820.

45. A comet was discovered by M. Pons on June 12th, 1819, which was observed until July 19th. Prof. Encké assigned to it an elliptic orbit, with a period of 5½ years.

46. A comet, discovered by Mr. Pigott at New York in 1783, was shown by Burckhardt to have an elliptic orbit, with a period of 5½ years.

47. On the 26th June, 1846, a comet was discovered at Naples by M. Peters, which was subsequently observed at Rome by De Vico, and continued to be seen until 21st July. An elliptic orbit is assigned to this comet, with a period of from thirteen to sixteen years, some uncertainty attending the observations. The reappearance of this comet may be expected in 1859, 1860.

48. A synoptical Table, showing the elements of the elliptic comets above described, may be seen by a reference to my "Hand-Book of Astronomy."

49. In fig. 2 (page 172), the orbits of these thirteen comets brought to a common plane, are represented roughly but in their

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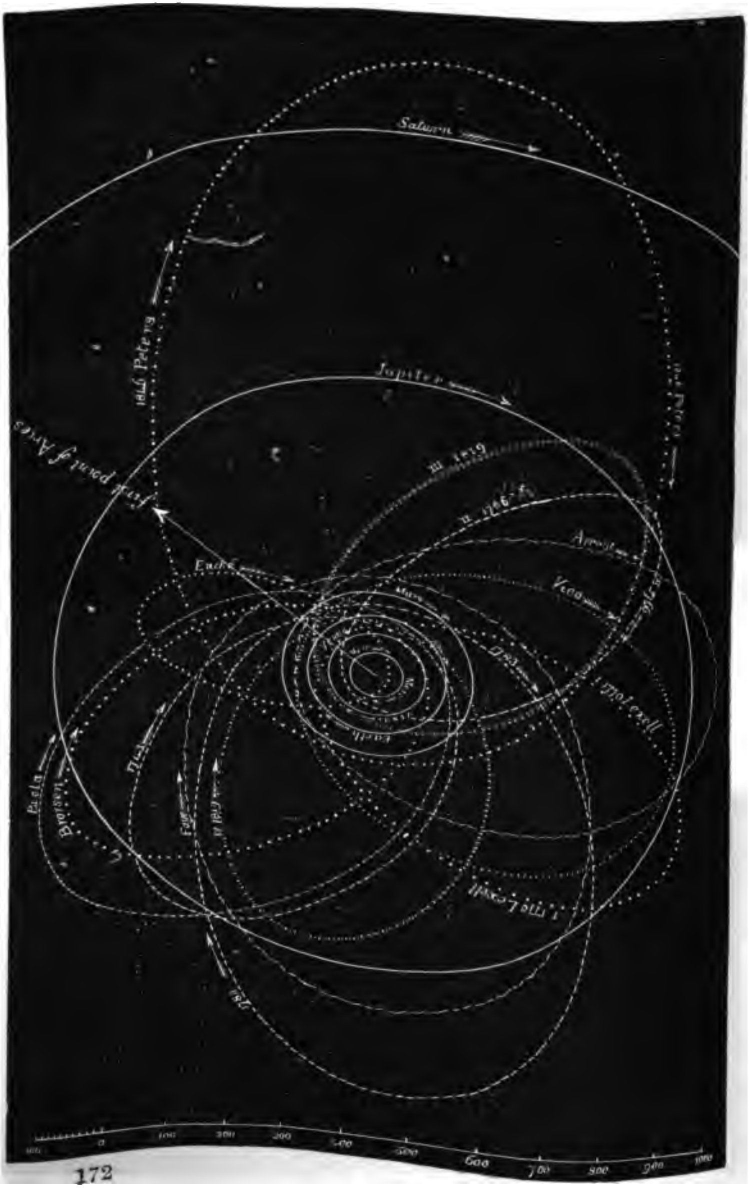
* Mém. Acad. des Sciences, 1847.

Fig. 2.


Saturn
Jupiter
1846 Peters
first point of Aries
Encke
Arrest
Vico
Mars
Venus
Mercury
Earth
Lexell
Biela
Brorsen
Tuttle
Faye
100
0
100
200
300
400
500
600
700
800
900
1000

proper proportions and relative positions, so as to exhibit to the eye their several ellipticities, and the relative directions of their axes.* All these bodies, without one exception, revolve in the common direction of the planets.

50. It is not alone, however, in the direction of their motions that the orbits of these bodies have an analogy to those of the planets. Their inclinations, with one exception, are within the limits of those of the planets. Their eccentricities, though incomparably greater than those of the planets, are, as will presently appear, incomparably less than those of all other comets yet discovered. Their mean distances and periods (with the exception of the last two in the Table just referred to) are within the limits of those of the planetoids.

The comparison of the numbers given in this Table with those in the Tables of the elements of other elliptic comets, and the comparison of the diagrams of their orbits with those of others, will show in a striking manner, to how great an extent the orbits of this group of comets possess the planetary character. Besides moving round the sun in the common direction, their inclinations, with a single exception, are within the limits of those of the planets. It is true that their eccentricities have an order of magnitude much greater; but on the other hand, it will be seen presently that they are incomparably less than the eccentricities of all other periodic comets yet discovered. Their mean distances and periods place them in direct analogy with the planetoids.

Moderate as are the eccentricities as compared with those of other comets, they are sufficiently great to impart a decided oval form to the orbits, and to produce considerable differences between the perihelion and aphelion distances, as will be apparent by inspecting the Table. It appears that while the perihelion of Enckê's comet lies within the orbit of Mercury, its aphelion lies outside the orbit of the most remote of the planetoids, and not far within that of Jupiter. The perihelion of Biela's comet, in like manner, lies between the orbits of the earth and Venus, while its aphelion lies outside that of Jupiter. In the case of Faye's comet, the least eccentric of the group, the perihelion lies near the orbit of Mars, and the aphelion outside that of Jupiter.

It must be remembered that the elliptic form of these orbits has only been verified by observations on the successive returns to perihelion of the first five comets in the Table. The elliptic elements of the others may, so far as is at present known, have been effaced by disturbing causes.

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* In the diagram, to prevent confusion, the orbits of the different comets are indicated by dotted or broken lines of different kinds.

The angular motions at the mean and extreme distances from the sun have been computed by the formulæ

$$\alpha = \frac{1,296000}{365{\cdot}25 \times \mathrm{P}}, \qquad \alpha' = \alpha \times \frac{a^2}{d'^2}, \qquad \alpha'' = \times\, \alpha \frac{a^2}{d''^2}.$$

In which α represents the mean angular velocity, α' the greatest, and α'', the least; d' the perihelion, and d'' the aphelion distances. P is the periodic time of the comet, and a the mean distance. The same numbers which express these angular motions, also express in all cases the intensities of solar light and heat in the several positions of the comet; and also the apparent motion of the sun, as seen from the comet; and a comparison of these with the corresponding numbers related to any of the planets, will illustrate in a striking manner how different are the physical conditions by which these two classes of bodies are affected; and this will be more and more striking, when the other groups of comets have been noticed.

Taking the comet of Enckć as an example, it appears that while its mean daily motion is 1076" or 18', its motion in aphelion is only 5', and in perihelion nearly 13°. Its motion in perihelion, the light and heat it receives from the sun, and the apparent motion of the sun as seen from it, are therefore severally more than 150 times greater in perihelion than in aphelion.

III.—ELLIPTIC COMETS, WHOSE MEAN DISTANCES ARE NEARLY EQUAL TO THAT OF URANUS.

51. It might be expected, that comets moving in elliptic orbits of small dimensions, and consequently having short periods, would have been the first in which the character of periodicity would be discovered. The comparative frequency of their returns to those positions near perihelion, where alone bodies of this class are visible from the earth, and the consequent possibility of verifying the fact of periodicity, by ascertaining the equality of the intervals between their successive returns to the same heliocentric position, to say nothing of the more distinctly elliptic form of the arcs of their orbits in which they can be immediately observed, would afford strong ground for such an expectation; nevertheless in this case, as has happened in so many others in the progress of physical knowledge, the actual results of observation and research have been directly contrary to such an anticipation; the most remarkable case of a comet of large orbit, long period, and rare returns, being the first, and those of small orbits, short

periods, and frequent returns, the last whose periodicity has been discovered.

52. It is evident that the idea of the possible existence of comets with periods shorter than those of the more remote planets, and orbits circumscribed within the limits of the solar system, never occurred to the mind either of Newton or any of his contemporaries or immediate successors.

In the third book of his PRINCIPIA, he calls comets a species of planets, revolving in elliptic orbits of a very oval form. But he continues, "I leave to be determined by others the transverse diameters and periods, by comparing comets which return *after long intervals of time* to the same orbits."

It is interesting to observe the avidity with which minds of a certain order snatch at such generalisations, even when but slenderly founded upon facts. These conjectures of Newton were soon after adopted by Voltaire: "Il y a quelque apparence," says he, in an essay on comets, "qu'on connaîtra un jour un certain nombre de ces autres planètes qui sous le nom de comètes tournent comme nous autour du soleil, mais il ne faut pas espérer qu'on les connaissent toutes."

And again, elsewhere, on the same subject:—

"Comètes, que l'on craint à l'égal du tonnerre,
Cessez d'épouvanter les peuples de la terre;
Dans une ellipse immense achevez votre cours,
Remontez, descendez près de l'astre des jours."

53. Extraordinary as these conjectures must have appeared at the time, they were soon strictly realised. Halley undertook the labour of examining the circumstances attending all the comets previously recorded, with a view to discover whether any, and which of them, appeared to follow the same path. He found that a comet which had been observed by himself, by Newton, and their contemporaries in 1682, followed a path while visible, which coincided so nearly with those of comets which had been observed in 1607, and in 1531, as to render it extremely probable, that these objects were the same identical comet, revolving in an elliptic orbit of such dimensions, as to cause its return to perihelion at intervals of 75—76 years.

The comet of 1682 had been well observed by La Hire, Picard, Hevelius, and Flamstead, whose observations supplied all the data necessary to calculate its path while visible. That of 1607 had been observed by Kepler and Longomontanus; and that of 1531, by Pierre Apian at Ingolstadt, the observations in both cases being also sufficient for the determination of the path of the body, with all the accuracy necessary for its identification.

54. Of the identity of the paths while visible on each of these appearances Halley entertained no doubt, and announced to the world the discovery of the elliptic motion of comets, as the result of combined observation and calculation, and entitled to as much confidence as any other consequence of an established physical law; and predicted the re-appearance of this body, on its succeeding return to perihelion in 1758-9. He observed, however, that as in the interval between 1607 and 1682 the comet passed near Jupiter, its velocity must have been augmented, and consequently its period shortened by the action of that planet. This period, therefore, having been only seventy-five years, he inferred that the following period would probably be seventy-six years or upwards; and consequently that the comet ought not to be expected to appear until the end of 1758, or the beginning of 1759. It is impossible to imagine any quality of mind more enviable than that which, in the existing state of mathematical physics, could have led to such a prediction. The imperfect state of science rendered it impossible for Halley to offer to the world a demonstration of the event which he foretold. "He therefore," says M. de Pontecoulant, "could only announce these felicitous conceptions of a sagacious mind as mere intuitive perceptions, which must be received as uncertain by the world, however he might have felt them himself, until they could be verified by the process of a rigorous analysis."

Subsequent researches gave increased force to Halley's prediction; for it appeared from the ancient records of observers, that comets had been seen in 1456 and 1378, whose elements were identical with those of the comet of 1682.

Fig. 26.—Feb. 7, 1836.

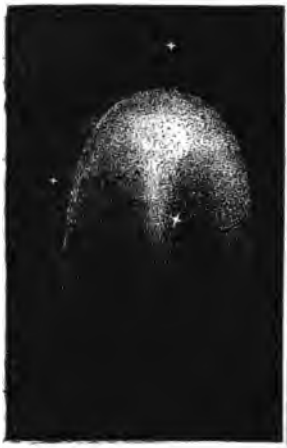
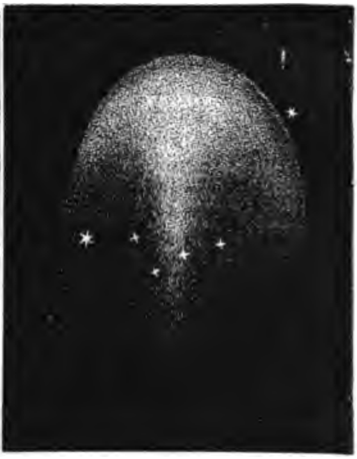


Fig. 28.—Feb. 16, 1836.



HALLEY'S COMET DEPARTING FROM THE SUN IN 1836.

COMETS.

CHAPTER III.

Halley's prediction (continued). — 55. Great advance of mathematical and physical sciences between 1682 and 1759.—56. Exact path of the comet on its return, and time of its perihelion, calculated and predicted by Clairaut and Lalande. — 57. Remarkable anticipation of the discovery of Uranus.—58. Prediction of Halley and Clairaut fulfilled by reappearance of the comet in 1758-9.—59. Disturbing action of a planet on a comet explained.—60. Effect of the perturbing action of Jupiter and Saturn on Halley's comet between 1682 and 1758.—61. Calculations of its return in 1835-36.—62. Predictions fulfilled.—63. Elements of the orbit of Halley's comet.—64. Pons's comet of 1812.—65. Olbers's comet of 1815.—66. De Vico's comet of 1846.—67. Brorsen's comet of 1847.—68. Westphal's comet of 1852.—69. Data necessary to determine the motions of these six comets.—70. Diagram of their orbits.—71. Planetary characters are nearly effaced in these orbits.—IV. Elliptic Comets, whose mean distances exceed the limits of the Solar System : 72. Synopsis of twenty-one elliptic comets of great eccentricity and long period.—73. Plan of the form and relative magnitude of the orbits.—V. 74. Hyperbolic Comets : VI. 75. Parabolic Comets.—VII. Physical constitution of Comets : 76. Apparent form—head and tail.—77.

Nucleus.—78. Coma.—79. Origin of the name.—80. Magnitude of the head.—81. Magnitude of the nucleus.—82. The tail.—83. Mass, density, and volume of comets.

THE appearance of the comet in 1456, was described by contemporary authorities to have been an object of "unheard-of magnitude;" it was accompanied by a tail of extraordinary length, which extended over sixty degrees (a third of the heavens), and continued to be seen during the whole of the month of June. The influence which was attributed to this appearance, renders it probable that in the record there exists more or less of exaggeration. It was considered as the celestial indication of the rapid success of Mohammed II., who had taken Constantinople, and struck terror into the whole Christian world. Pope Calixtus II. levelled the thunders of the Church against the enemies of his faith, terrestrial and celestial, and in the same bull exorcised the Turks and the comet; and in order that the memory of this manifestation of his power should be for ever preserved, he ordained that the bells of all the churches should be rung at midday—a custom which is preserved in those countries to our times. It must be admitted that, notwithstanding the terrors of the Church, the comet pursued its course with as much ease and security, as those with which Mohammed converted the church of St. Sophia into his principal mosque.

The extraordinary length and brilliancy which was ascribed to the tail upon this occasion, have led astronomers to investigate the circumstances under which its brightness and magnitude would be the greatest possible; and, upon tracing back the motion of the comet to the year 1456, it has been found that it was then actually under the circumstances of position with respect to the earth and sun most favourable to magnitude and splendour. So far, therefore, the results of astronomical calculation corroborate the records of history.

55. In the interval of three-quarters of a century, which elapsed between the announcement of Halley's prediction and the date of its expected fulfilment, great advances were made in mathematical science; new and improved methods of investigation and calculation were invented; and, the theory of gravitation was pursued with extraordinary activity and success through its consequences in the mutual disturbances produced upon the motions of the planets and satellites, by the attraction of their masses one upon another. As the epoch of the expected return of the comet to its perihelion approached therefore, the scientific world resolved to divest, as far as possible, the prediction, of that vagueness which necessarily attended it owing to the imperfect state of science at the time it was made, and to calculate the exact effects

of those planets whose masses were sufficiently great, in accelerating or retarding its motion while passing near them.

56. This inquiry, which presented great mathematical difficulties and involved enormous arithmetical labour, was undertaken by Clairaut and Lalande: the former, a mathematician and natural philosopher, who had already applied with great success the principles of gravitation to the motions of the moon, undertook the purely analytical part of the investigation, which consisted in establishing certain general algebraical formulæ, by which the disturbing actions exerted by the planets on the comet were expressed; and Lalande, an eminent practical astronomer, undertook the labour of the arithmetical computations, in which he was assisted by a lady, Madame Lepaute, whose name has thus become celebrated in the annals of science.

When it is considered that the period of Halley's comet is about seventy-five years, and that for two successive periods, it was necessary to calculate every portion of its course separately in this way, some notion may be formed of the labour encountered by Lalande and Madame Lepaute. "During six months," says Lalande, "we calculated from morning till night, sometimes even at meals; the consequence of which was, that I contracted an illness which changed my constitution for the remainder of my life. The assistance rendered by Madame Lepaute was such, that without her we never could have dared to undertake this enormous labour, in which it was necessary to calculate the distance of each of the two planets, Jupiter and Saturn, from the comet, and their attraction upon that body, separately, for every successive degree, and for 150 years."

The name of Madame Lepaute does not appear in Clairaut's memoir; a suppression which Lalande attributes to the influence exercised by another lady to whom Clairaut was attached. Lalande, however, quotes letters of Clairaut, in which he speaks in terms of high admiration of "la savante calculatrice." The labours of this lady in the work of calculation (for she also assisted Lalande in constructing his "Ephemerides") at length so weakened her sight that she was compelled to desist. She died in 1788, while attending on her husband, who had become insane. See the article on comets, by Prof. de Morgan, in the "Companion to the British Almanac" for the year 1833.

These elaborate calculations being completed, Clairaut presented the result of their joint labours, in a memoir to the Academy of Sciences of Paris, in which he predicted the next arrival of the comet at perihelion, on the 18th of April, 1759; a date, however, which, before the re-appearance of the comet, he found reason to change to the 11th of April; and assigned the path which the comet would follow while visible as determined by the following data:—

Inclination.	Longitude of node.	Longitude of perihelion.	Perihelion distance.	Direction.
17° 37′	53° 50′	303° 10′	0·58	retrograde.

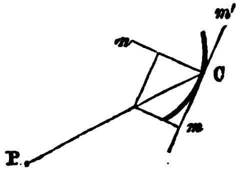
57. In announcing his prediction Clairaut stated, that the time assigned for the approaching perihelion might vary from the actual time to the extent of a month; for that independently of any error either in the methods or process of calculation, the event might deviate more or less from its predicted occurrence, by reason of the attraction of *an undiscovered planet of our system revolving beyond the orbit of Saturn.* In twenty-two years after this time this conjecture was realised, by the discovery of the planet Uranus, by the late Sir William Herschel, revolving round the sun one thousand millions of miles beyond the orbit of Saturn!

58. The comet, in fine, appeared in December 1758, and followed the path predicted by Clairaut, which differed but little from that which it had pursued on former appearances. It passed through perihelion on the 13th of March, within twenty-two days of time, and within the limit of the possible errors assigned by Clairaut.

59. The general effects of a planet in accelerating or retarding the motion of a comet are easily explained, although the exact details of the disturbances are too complicated to admit of any exposition here.

Let P, fig. 3, represent the place of the disturbing planet, and C that of the comet. The attraction of the planet on the comet will then be a force directed from C towards P, and by the principle of the composition of forces is equivalent to two components, one C *m* in the direction of the comet's path, and the other C *n* perpendicular to that path. If the motion of the comet be directed from C towards *m*, it will be accelerated; and if it be directed from C towards *m′*, it will be retarded by that component of the planet's attraction which is directed from C to *m*. The other component C *n* being at right angles to the comet's motion, will have no direct effect either in accelerating or retarding it.

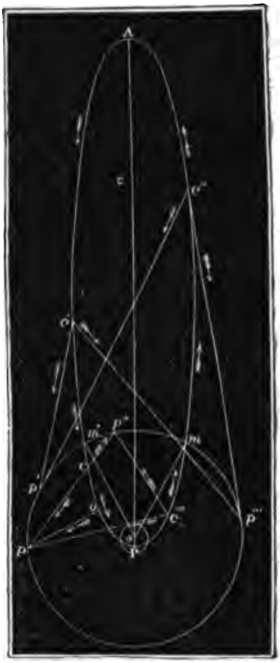
Fig. 3.



It appears, therefore, in general that, if the direction of the comet's motion C *m* make an acute angle with the line C P drawn to the planet, the planet's attraction will accelerate it; and if its direction C *m'* make an obtuse angle with the line C P, it will retard it.

This being understood, the disturbing action of a planet such as Jupiter or Saturn on a comet such as Halley's may be easily comprehended. In fig. 4, the orbit of the comet is represented at A *c* P *c''* in its proper proportions, A P being the major axis, P the place of perihelion, A that of aphelion, and S that of the focus in which the sun is placed. The small circle described round S represents in its proper proportions the orbit of the earth, whose distance is about twice that of the comet when the latter is at perihelion. The circle *p p' p''* represents in its proper proportions the orbit of Jupiter which, for illustration, we shall consider as the disturbing planet.

Fig. 4.



It will be apparent on the mere inspection of the diagram, that lines drawn from the planet whatever be its place, to any point whatever of the comet's path between its aphelion A, and the point *m'* where it arrives at the orbit of the planet in approaching the sun, will make acute angles with the direction of the comet's motion; and that, consequently, the comet will be accelerated by the action of the planet. In like manner, it is apparent that lines drawn from the planet whatever be its place, to any point whatever of the comet's path between *m* and aphelion A, will make obtuse angles with the direction of the comet's motion; and, consequently, the comet will be retarded by the action of the planet, in departing from the sun, from *m* to A.

In that part of the comet's path which lies within the planet's orbit, the action of the planet alternately accelerates and retards it, according to their relative position. If the planet be at *p*, suppose *p o* drawn so as to be at right angles to the path of the comet. Between *m'* and *o* the action of the planet at *p* will accelerate the comet, and after the comet passes *o* it will retard it. In like manner if the planet be at *p''*, it will first retard the motion of the comet proceeding from *m′* through P towards A, and will continue to do so until the line of direction becomes perpendicular to that of the comet's motion, after which it will accelerate it.

It appears, therefore, that during the period of the comet, the disturbing action of the planet is subject to several changes of direction, owing partly to the change of position of the comet and partly to that of the planet; and the total effect of the disturbing action of the planet on the comet's period is found by taking the difference between the total amount of all the accelerating and all the retarding actions.

In the case of the planet Jupiter and Halley's comet, the former makes nearly seven complete revolutions in a single period of the comet; and consequently its disturbing action is not only subject to several changes of direction, but also to continual variation of intensity, owing to its change of distance from the comet.

Small as the arc *m′* P *m* of the comet's path is which is included within the orbit of Jupiter, the fraction of the period in which this arc is traversed by the comet is much smaller, as will be apparent by considering the application of the principle of equable areas * to this case. The time taken by the comet to move over the arc *m′* P *m* is in the same proportion to its entire period, as the area included between the arc *m′* P *m* and the lines *m′* S and *m* S is to the entire area of the ellipse A P.

To simplify the explanation the orbit of the comet has here been supposed to be in the plane of that of the disturbing planet. If it be not, the disturbing action will have another component at right angles to the plane of the comet's orbit, the effect of which will be a tendency to vary the inclination.

60. The result of the investigation by Clairaut showed, that the total effect of the disturbing action of Jupiter and Saturn on Halley's comet between its perihelions in 1682 and in 1759, was to increase its period by 618 days as compared with the time of its preceding revolution, of which increase, 100 days were due to the action of Saturn, and 518 to that of Jupiter.

Clairaut did not take into account the disturbing action of the earth, which was not altogether inconsiderable, and could not allow for those of the undiscovered planets, Uranus and Neptune. The effects of the action of the other planets, Mars, Venus, Mercury, and the planetoids, are in these cases insignificant.

61. In the interval of three quarters of a century which preceded the next re-appearance of this comet, science continued to progress, and instruments of observation and principles and

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* See "Handbook of Astronomy," chap. xii. § 2599.

methods of investigation were still further improved; and, above all, the number of observers was greatly augmented. Before the epoch of its return in 1835, its motions, and the effects produced upon them by the disturbing action of the several planets, were computed by MM. Damoiseau, Pontecoulant, Rosenberger, and Lehmann, who severally predicted its arrival at perihelion:—

Damoiseau	4th Nov. 1835.
Pontecoulant	7th ,,
Rosenberger	11th ,,
Lehmann	26th ,,

62. These predictions were all published before July, 1835. The comet was seen at Rome on the 5th August, in a position within *one degree* of the place assigned to it for that day, in the ephemeris of M. Rosenberger. On the 20th August, it became visible to all observers, and pursued the course with very little deviation, which had been assigned to it in the ephemerides, arriving at its perihelion on the 16th Nov., being very nearly a mean between the four epochs assigned in the predictions.

After this, passing south of the equator, it was not visible in northern latitudes, but continued to be seen in the southern hemisphere until the 5th of May, 1836, when it finally disappeared, not again to return until the year 1911.

63. A synoptical Table of the elements of the orbit of this comet, deduced from the observations made on each of its seven successive returns to perihelion, between 1378 and 1835 inclusive, may be seen by a reference to the "Hand-Book of Astronomy."

It appears that the mean distance of this comet is about eighteen times that of the earth, and that it is consequently at a little less than the mean distance of Uranus. When in perihelion, its distance from the sun is about half the earth's distance, while its distance in aphelion is above thirty-five times the earth's distance, and therefore seventy times its perihelion distance.

64. On the 20th of July, 1812, a comet was discovered by M. Pons, whose orbit was calculated by Professor Encké, and was found to be an ellipse of such dimensions as to give a period of 75½ years, equal to that of Halley's comet.

65. On the 6th of March, 1815, Dr. Olbers discovered at Bremen, a comet whose orbit, calculated by Professor Bessel, proved to be an ellipse, with a period of 74 years. The next perihelion passage of this comet is predicted for the 9th of February, 1887.

66. On the 28th of February, 1846, M. de Vico discovered a comet at Rome, whose orbit, calculated by MM. van Deinse and Pierce, appears to be an ellipse, with a period of 72-73 years.

67. A comet was discovered by M. Brorsen at Altona, on the 20th of July, 1847; the orbit of which, calculated by M. d'Arrest, appears to be an ellipse, with a period of 75 years.

68. On the 27th of June, 1852, a comet was discovered by M. Westphal at Gottingen, and was soon afterwards observed by M. Peters at Constantinople. The calculation of its orbit proves it to be an ellipse, with a period of about 70 years.

69. A synoptical Table, presenting the data necessary to determine the motions of these six comets, may be seen by a reference to the "Hand-Book of Astronomy."

70. In fig. 5 (p. 145), is presented a plan of the orbits, brought upon a common plane, and drawn according to the scale indicated. This figure shows, in a manner sufficiently exact for the purposes of illustration, the relative magnitudes and the forms of the six orbits, as well as the directions of their several axes with relation to that of the first point of Aries.

71. By comparing the elements given in the table referred to above, and the forms and magnitudes of the orbits shown in the diagram, with those of the first group of elliptic comets given in Table III, "Hand-Book of Astronomy," chap. XVIII, and drawn in fig. 2 (p. 172), it will be perceived that the planetary characteristics noticed in the latter group, are nearly effaced. Five of the six comets composing the second group, revolve in the common direction of the planets, and this is the only planetary character observable among them. The inclinations, no longer limited to those of the planetary orbits, range from 18° to 74°. The eccentricities are all so extreme, that the arc of the orbit near perihelion approximates closely to the parabolic form, and the most remarkable body of the group, the comet of Halley, revolves in a direction contrary to the common motion of the planets.

But it is more than all in the elongated oval form of their orbits, that this group of comets differs, not only from the planets, but from the first group. While their perihelia are at distances from the sun, between those of Mars and Mercury, their aphelia are from two to five hundred millions of miles outside the orbit of Neptune. Thus, the comet of Halley, for example, in perihelion, is at a distance from the sun less than that of Venus; but at its aphelion, its distance exceeds that of Neptune by a space greater than Jupiter's distance from the sun. The mean angular motion of this comet is nearly the same as that of Uranus; but its angular motion in perihelion is three times that of Mercury;

while its angular motion in aphelion is little more than half that of Neptune.

The corresponding variations of solar light and heat, and of the apparent magnitude and motion of the sun as seen from the comet, may be easily inferred.

IV.—ELLIPTIC COMETS WHOSE MEAN DISTANCES EXCEED THE LIMITS OF THE SOLAR SYSTEM.

72. Although the periodicity of this class of comets has not yet in any instance been certainly established by observations made upon their successive returns to perihelion, the observations made upon them during a single perihelion passage indicate an arc of their orbit, which exhibits the elliptic form so unequivocally, as to supply computers and mathematicians with the data necessary to obtain, with more or less approximation, the value of the eccentricity, which, combined with the perihelion distance, gives the form and magnitude of the comet's orbit.

By calculations conducted in this manner, and applied to the observations made on various comets which have appeared since the latter part of the seventeenth century, the elliptic orbits of twenty-one of these bodies have been computed, and are given in the order of the dates of their perihelion passages in a table which will be found in my "Hand-Book of Astronomy."

Of this group the least eccentric is No. 15, which passed its perihelion in 1840. This comet was discovered at Berlin by M. Bremiker, and its orbit was calculated by Götze, and proved to be an ellipse, having the elements given in the table, subject to no greater uncertainty than $\frac{1}{64}$th of the value assigned to the mean distance. The eccentricity, and consequently the form of the orbit, is similar to that of Halley, but the major axis is $2\frac{2}{3}$ times, and the period nearly five times greater. Its perihelion distance is equal to that of Mars, and its aphelion distance more than three times that of Neptune.

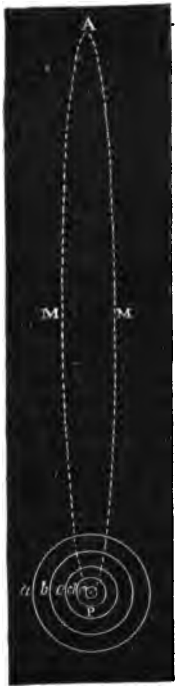
No. 6, which passed its perihelion in 1793, has an orbit, according to the calculations of D'Arrest, nearly similar both in form and magnitude, as will be seen by comparing the numbers given in the table. More uncertainty, however, attends the estimation of these elements.

The comets which approached nearest to the sun were the great comets of 1680 and 1843, Nos. 1 and 16 in the table, both memorable for their extraordinary magnitude and splendour.

The elements of that of 1680, given in the table, are those which have resulted from the calculations of Professor Enckê, based on all the observations of the comet which have been recorded. The elements of the great comet of 1843 have resulted from the computations of Mr. Hubbard. Both are subject to considerable uncertainty, and must be accepted only as the best approximations that can be obtained.

What is not subject, however, to the same uncertainty, is the extraordinary proximity of these bodies to the sun at their respective perihelia. The perihelion distance of the comet of 1680 was about 576000 miles, and that of 1843, 538000 miles. Now the semidiameter of the sun being 441000 miles, it follows that the distance of the centres of those comets respectively from the surface of the sun at perihelion must have been only 235000 and 97000; so that if the semidiameter of the nebulous envelope of either of them exceeded this distance, they must have actually grazed the sun.

Fig. 6.



The velocity of the orbital motion of these bodies in perihelion appears by the table to be such, that the comet of 1680 would have revolved round the sun in a minute, and that of 1843 in a little less than two minutes, if they retained the same angular motion undiminished.

The distance to which the comet of 1680 recedes in its aphelion is 28½ times greater than that of Neptune. The apparent diameter of the sun seen from that distance would be 2″, and the intensity of its light and heat would be 730000 times less than at the earth; while their intensity at the perihelion distance would be 26000 times greater, so that the light and heat received by the comet in its aphelion would be 26000 × 730000 = 18980 million times less than in perihelion.

The greatest aphelion distances in the table are those of Nos. 5, 13, and 17, the comets of 1780, 1830, and 1844, amounting to from 100 to 140 times the distance of Neptune; the eccentricities differing from unity by less than $\frac{1}{1000}$. These orbits, though strictly the results of calculation, must be regarded as subject to considerable uncertainty.

73. To convey an idea of the form of the orbits of the comets of this group, and of the proportion which their magnitude bears to the dimensions of the solar system, we have drawn in

fig. 6, an ellipse, which may be considered as representing the form of the orbits of the comets Nos. 15, 6, 9, 12, and 1, of Table VI in the "Handbook of Astronomy."

If the ellipse represent the orbit of the comet No. 15, the circle *a* will represent on the same scale the orbit of Neptune.

If the ellipse represent the orbit of the comet No. 6, the circle *b* will represent the orbit of Neptune.

If the ellipse represent the orbit of No. 9, the circle *c* will represent the orbit of Neptune.

If the ellipse represent the orbit of No. 12, the circle *d* will represent the orbit of Neptune.

If the ellipse represent the orbit of No. 1, the circle *e* will represent the orbit of Neptune.

V.—HYPERBOLIC COMETS.

74. In a Table in the "Hand-Book of Astronomy" are given the elements of seven comets which appear by the results of calculations made upon the observations to have passed through the system in hyperbolic orbits.

VI.—PARABOLIC COMETS.

75. Of all the remaining number of comets which have been seen in the heavens and recorded in history, one hundred and sixty-one have been observed with sufficient precision to enable astronomers to determine, with more or less approximation, their parabolic orbits. A table giving the elements of these, with the dates of their appearance, will be found in the eighteenth chapter of the "Handbook of Astronomy."

VII.—PHYSICAL CONSTITUTION OF COMETS.

76. Comets in general, and more especially those which are visible without a telescope, present the appearance of a roundish mass of illuminated vapour or nebulous matter, to which is often, though not always, attached a train more or less extensive, composed of matter having a like appearance. The former is called the HEAD, and the latter the TAIL, of the comet.

77. The illumination of the head is not generally uniform. Sometimes a bright central spot is seen in the nebulous matter which forms it. This is called the NUCLEUS.

The nucleus sometimes appears as a bright stellar point, and sometimes presents the appearance of a planetary disc seen through a nebulous haze. In general, however, on examining the object with high optical power, these appearances are changed, and the object seems to be a mere mass of illuminated vapour from its borders to its centre.

78. When a nucleus is apparent, or supposed to be so, the nebulous haze which surrounds it and forms the exterior part of the head is called the *coma*.

79. These designations are taken from the Greek word κομή (komê) hair, the nebulous matter composing the coma and tail being supposed to resemble hair, and the object being therefore called κομήτης (kometes), a hairy star.

80. As the brightness of the coma gradually fades away towards the edges, it is impossible to determine with any great degree of precision its real dimensions. These, however, are obviously subject to enormous variation, not only in different comets compared one with another, but even in the same comet during the interval of a single perihelion passage. The greatest of those which have been submitted to micrometrical measurement was the great comet of 1811, the diameter of the head of which was found to be not less than 1⅛ millions of miles, which would give a volume greater than that of the sun in the ratio of about 2 to 1. The diameter of the head of Halley's comet when departing from the sun, in 1836, at one time measured 357000 miles, giving a volume more than sixty times that of Jupiter. These are, however, the greatest dimensions which have been observed in this class of objects, the diameter rarely exceeding 200000 miles, and being generally less than 100000.

81. Attempts have been made where nuclei were perceivable, to estimate their magnitude, and diameters have been assigned to them, varying from 100 to 5000 miles. For the reasons, however, already explained, these results must be regarded as very doubtful.

Those who deny the existence of solid matter within the coma, maintain that even the most brilliant and conspicuous of those bodies, and those which have presented the strongest resemblance to planets, are more or less transparent. It might be supposed that a fact so simple as this, in this age of astronomical activity, could not remain doubtful; but it must be considered, that the combination of circumstances which alone would test such a question, is of rare occurrence. It would be necessary that the centre of the head of the comet, although very small, should pass critically over a star, in order to ascertain whether such star is visible through it. With comets having extensive comæ without nuclei, this has sometimes occurred; but we have not had such satisfactory examples in the more rare instances of those which have distinct nuclei.

In the absence of a more decisive test of the occultation of a star by the nucleus, it has been maintained that the existence of a solid nucleus may be fairly inferred from the great splendour which has attended the appearance of some comets. A mere mass of vapour could not, it is contended, reflect such brilliant light. The following are the examples adduced by Arago :—

"In the year 43 before Christ, a comet appeared which was said to be visible to the naked eye by daylight. It was the comet which the Romans considered to be the soul of Cæsar transferred to the heavens after his assassination.

"In the year 1402 two remarkable comets were recorded. The first was so brilliant that the light of the sun at noon, at the end of March, did not prevent its nucleus, or even its tail, from being seen. The second appeared in the month of June, and was visible also for a considerable time before sunset.

"In the year 1532, the people of Milan were alarmed by the appearance of a star which was visible in the broad daylight. At that time Venus was not in a position to be visible, and consequently it is inferred that this star must have been a comet.

"The comet of 1577 was discovered on the 13th of November by Tycho Brahe, from his observatory on the isle of Huene, in the Sound, before sunset.

"On the 1st of February, 1744, Chizeaux observed a comet more brilliant than the brightest star in the heavens, which soon became equal in splendour to Jupiter, and in the beginning of March it was visible in the presence of the sun. By selecting a proper position for observation, on the 1st of March it was seen at one o'clock in the afternoon without a telescope."

Such is the amount of evidence which observation has supplied respecting the existence of a solid nucleus. The most that can be said of it is, that it presents a plausible argument, giving some probability, but no positive certainty, that comets have visited our system which have solid nuclei, but, meanwhile, this can only be maintained with respect to a few : most of those which have been seen, and all to which very accurate observations have been directed, have afforded evidence of being mere masses of semi-transparent matter.

82. Although by far the great majority of comets are not attended by tails, yet that appendage, in the popular mind, is more inseparable from the idea of a comet than any other attribute of these bodies. This proceeds from its singular and striking appearance, and from the fact that most comets visible to the naked eye have had tails. In the year 1531, on the occasion of

one of the visits of Halley's comet to the solar system, Pierre Apian observed that the comet generally presented its tail in the direction opposite to that of the sun. This principle was hastily generalised, and is even at present too generally adopted. It is true that in most cases the tail extends itself from that part of the comet which is most remote from the sun; but its direction rarely corresponds with the direction which the shadow of the comet would take. Sometimes it has happened that the tail forms with a line drawn to the sun a considerable angle, and cases have occurred when it was actually at right angles to it.

Another character which has been observed to attach to the tails of comets, which, however, is not invariable, is, that they incline constantly toward the region last quitted by the comet, as if in its progress through space it were subject to the action of some resisting medium, so that the nebulous matter with which it is invested, suffering more resistance than the solid nucleus, remains behind it and forms the tail.

The tail sometimes appears to have a curved form. That of the comet of 1744 formed almost a quadrant. It is supposed that the convexity of the curve, if it exists, is turned in the direction from which the comet moves. It is proper to state, however, that these circumstances regarding the tail have not been clearly and satisfactorily ascertained.

The tails of comets are not of uniform breadth or diameter; they appear to diverge from the comet, enlarging in breadth and diminishing in brightness as their distance from the comet increases. The middle of the tail usually presents a dark stripe, which divides it longitudinally into two distinct parts. It was long supposed that this dark stripe was the shadow of the body of the comet, and this explanation might be accepted if the tail was always turned from the sun; but we find the dark stripe equally exists when the tail, being turned sideways, is exposed to the effect of the sun's light.

This appearance is usually explained by the supposition that the tail is a hollow, conical shell of vapour, the external surface of which possesses a certain thickness. When we view it, we look through a considerable thickness of vapour at the edges, and through a comparatively small quantity at the middle. Thus upon the supposition of a hollow cone, the greatest brightness would appear at the sides, and the existence of a dark space in the middle would be perfectly accounted for.

The tails of comets are not always single; some have appeared at different times with several separate tails. The comet of 1744, which appeared on the 7th or 8th of March, had six tails, each about 4° in breadth, and from 30° to 44° in length. Their sides were well defined and tolerably bright, and the spaces between them were as dark as the other parts of the heavens.

The tails of comets have frequently appeared, not only of immense real length, but extending over considerable spaces of the heavens. It will be easily understood that the apparent length depends conjointly upon the real length of the tail, and the position in which it is presented to the eye. If the line of vision be at right angles to it, its length will appear as great as it can do at its existing distance; if it be oblique to the eye, it will be foreshortened, more or less, according to the angle of obliquity. The real length of the tail is easily calculated when the apparent length is observed and the angle of obliquity known.

In respect of magnitude, the tails are unquestionably the most stupendous objects which the discoveries of the astronomer have ever presented to human contemplation.

The following are the results of the observation and measurement of a few of the more remarkable.

Table.	No.	Date of Appearance.	Greatest observed Length of Tail.
			miles.
VIII	148	1847	5000000
—	73	1744	19000000
VI	4	1769	40000000
VIII	46	1618	50000000
VI	1	1680	100000000
—	8	1811	100000000
—	9	1811	130000000
—	16	1843	200000000

The magnitude of these prodigious appendages is even less amazing than the brief period in which they sometime emanate from the head. The tail of the comet of 1843, long enough to stretch from the sun to the planetoids, was formed in less than twenty days.

83. The masses of comets, like those of the planets, would be ascertained if the reciprocal effects of their gravitation and those of any known bodies in the system could be observed. But although the disturbing action of the planets on these bodies is conspicuous, and its effects have been calculated and observed, not the slightest effect of the same kind has ever been ascertained to be produced by them, even upon the smallest bodies in the system, and those to which comets have approached most nearly.

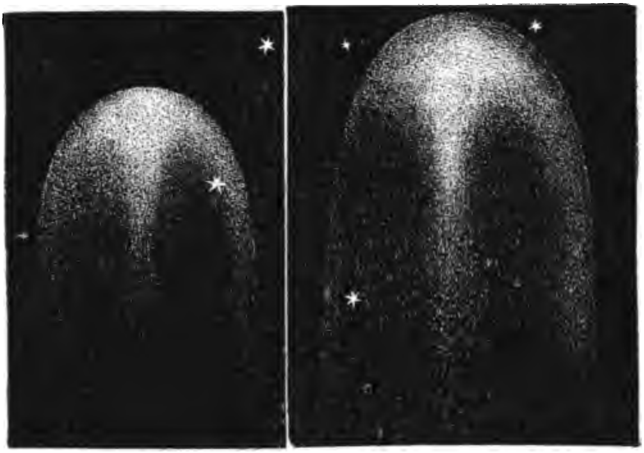
In fine, notwithstanding the enormous number of comets, observed and unobserved, which constantly traverse the solar system in all conceivable directions; notwithstanding the permanent revolution of the periodic comets, whose presence and orbits have been ascertained; notwithstanding the frequent visits of comets, which so thoroughly penetrate the system as almost to touch the surface of the sun at their perihelion, the motions of the various bodies of the system, great and small, planets major and minor, planetoids and satellites, go on precisely as if no such bodies as the comets approached their neighbourhood. Not the smallest effects of the attraction of such visitors are discoverable.

Now since, on the other hand, the disturbing effects of the planets upon the comets are strikingly manifest, and since the comets move in elliptic, parabolic, or hyperbolic orbits, of which the sun is the common focus, it is demonstrated that these bodies are composed of ponderable matter, which is subject to all the consequences of the law of gravitation. It cannot, therefore, be doubted that the comets do produce a disturbing action on the planets, although its effects are inappreciable even by the most exact observation. Since, then, the disturbances mutually produced are in the proportion of the disturbing masses, it follows that the masses of the comets must be smaller beyond all calculation than the masses even of the smallest bodies among the planets primary or secondary.

The volumes of comets in general exceed those of the planets in a proportion nearly as great as that by which the masses of the planets exceed those of the comets. The consequence obviously resulting from this, is that the density of comets is incalculably small.

Their densities in general are probably thousands of times less than that of the atmosphere in the stratum next the surface of the Earth.

Fig. 27.—February 10, 1836. Fig. 29.—February 23, 1836.



HALLEY'S COMET DEPARTING FROM THE SUN IN 1836.

COMETS.

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CHAPTER IV.

84. Light of comets.—85. Enlargement of magnitude on departing from the sun.—86. Professor Struve's drawings of Enckė's comet.—87. Remarkable physical phenomena manifested by Halley's comet.—88. Struve's drawings of the comet approaching the sun in 1835.—89. Its appearance on the 29th of Sept.—90. Appearance on Oct. 3.—91. Appearance on Oct. 6.—92. Appearance on Oct. 9.—93. Appearance on Oct. 10.—94. Appearance on Oct. 12.—95. Appearance on Oct. 14.—96. Appearance on Oct. 29.—97. Appearance on Nov. 5.—98. Sir J. Herschel's deductions from these phenomena.—99. Appearance of the comet after perihelion.—100. Observations and drawings of MM. Maclear and Smith.—101. Appearance on Jan. 24.—102. Appearance on Jan. 25.—103. Appearance on Jan. 26.—104. Appearance on Jan. 27.—105. Appearance on Jan. 28.—106. Appearance on Jan. 30.—107. Appearance on Feb. 1.—108. Appearance on Feb. 7.—109. Appearance on Feb. 10.—110. Appearance on Feb. 16 and 23.—111. Number of comets.—112. Duration of the appearance of comets.—113. Near approach of comets to the earth.

84. That planets are not self-luminous, but receive their light from the sun, is proved by their phases, and by the shadows of

their satellites, which are projected upon them, when the latter are interposed between them and the sun. These tests are inapplicable to comets. They exhibit no phases, and are attended by no bodies to intercept the sun's light. But, unless it could be shown that a comet is a solid mass, impenetrable to the solar rays, the non-existence of phases is not a proof that the body does not receive its light from the sun.

A mere mass of cloud or vapour, though not self-luminous, but rendered visible by borrowed light, would still exhibit no effect of this kind: its imperfect opacity would allow the solar light to affect its constituent parts throughout its entire depth—so that, like a thin fleecy cloud, it would appear not superficially illuminated, but receiving and reflecting light through all its dimensions. With respect to comets, therefore, the doubt which has existed is, whether the light which proceeds from them, and by which they become visible, is a light of their own, or is the light of the sun shining upon them, and reflected to our eyes like light from a cloud. Among several tests which have been proposed to decide this question, one suggested by Arago merits attention.

It has been already shown in our Tract on "the Eye" (43), that the apparent brightness of a visible object is the same at all distances, supposing its real brightness to remain unchanged. Now if comets shone with their proper light, and not by light received from the sun, their apparent brightness would not decrease as they would recede from the sun, and they would cease to be visible, not because of the faintness of their light, but because of the smallness of their apparent magnitude. Now the contrary is found to be the case. As the comet retires from the sun its apparent brightness rapidly decreases, and it ceases to be visible from the mere faintness of its light, while it still subtends a considerable visual angle.

85. It will doubtless excite surprise, that the dimensions of a comet should be enlarged as it recedes from the source of heat. It has been often observed in astronomical inquiries, that the effects, which at first view seem most improbable, are nevertheless those which frequently prove to be true; and so it is in this case. It was long believed that comets enlarged as they approached the sun; and this supposed effect was naturally and probably ascribed to the heat of the sun expanding their dimensions. But more recent and exact observations have shown the very reverse to be the fact. Comets increase their apparent volume as they recede from the sun; and this is a law to which there appears to be no well-ascertained exception. This singular and unexpected phenomenon has been attempted to be accounted

for in several ways. Valz ascribed it to the pressure of the solar atmosphere acting upon the comet; that atmosphere being more dense near the sun, compresses the comet and diminishes its dimensions; and, at a greater distance, being relieved from this coercion, the body swells to its natural bulk. A very ingenious train of reasoning was produced in support of this theory. The density of the solar atmosphere and the elasticity of the comet, being assumed to be such as they might naturally be supposed, the variations of the comet's bulk are deduced by strict reasoning, and show a surprising coincidence with the observed change in the dimensions. But this hypothesis is tainted by a fatal error. It proceeds upon the supposition that the comet, on the one hand, is formed of an elastic gas or vapour; and, on the other, that it is impervious to the solar atmosphere through which it moves. To establish the theory, it would be necessary to suppose that the elastic fluid composing the comet should be surrounded by a *nappe* or envelope as elastic as the fluid composing the comet, and yet wholly impenetrable by the solar atmosphere.

Several ingenious hypotheses * have been proposed and successively rejected for explaining this phenomenon, but it seems now agreed to ascribe it to the action of the varying temperature to which the vapour which composes the nebulous envelope is exposed. As the comet approaches the sun, this vapour is converted by intense heat into a pure, transparent, and therefore invisible elastic fluid. As it recedes from the sun, the temperature decreasing, it is partially and gradually condensed, and assumes the form of a semitransparent visible cloud, as steam does escaping from the valve of a steam boiler. It becomes more and more voluminous as the distance from the source of heat, and therefore the extent of condensation, is augmented.

86. Professor Struve made a series of observations on the comet of Encké, at the period of its reappearance in 1828, and by the aid of the great Dorpat telescope, made the drawings figs. 7 and 8.

Fig. 7 represents the comet as it appeared on the 7th November, the diameter *a b* measuring 18′. The brightest part of the comet extended from *k* to *l*, and was consequently eccentric to it, the distance of the centre of brightness from the centre of magnitude being *k* K. Between the 7th and the 30th November, the magnitude of the comet decreased from that represented in fig. 7, to that represented in fig. 8; but the apparent brightness was so much increased, that at the latter date it was visible to the naked eye as a star of the 6th magnitude. The apparent diameter was then reduced to 9′.

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* For several of these, see Sir J. Herschel's memoir, "Proceedings of Astronomical Society," vol. vi. p. 104.

On November 7th a star of the 11th magnitude was seen through the comet, so near the centre of brightness that it was for a moment mistaken for a nucleus. The brightness of the star was not in the least perceptible degree dimmed by the mass of cometary matter through which its light passed.

It was evident that the increase of the brightness of the comet on the 30th November, must be ascribed to the contraction, and consequent condensation, of the nebulous matter composing it in receding from the sun, for its distance from the earth on the 7th November, when it subtended an angle of 18′, was 0·515 (the earth's mean distance from the sun being =1); while its distance on the 30th, when it subtended an angle of 9′, was only 0·477. Its cubical dimensions must, therefore, have been diminished, and the density of the matter composing it augmented in more than eight-fold proportion.

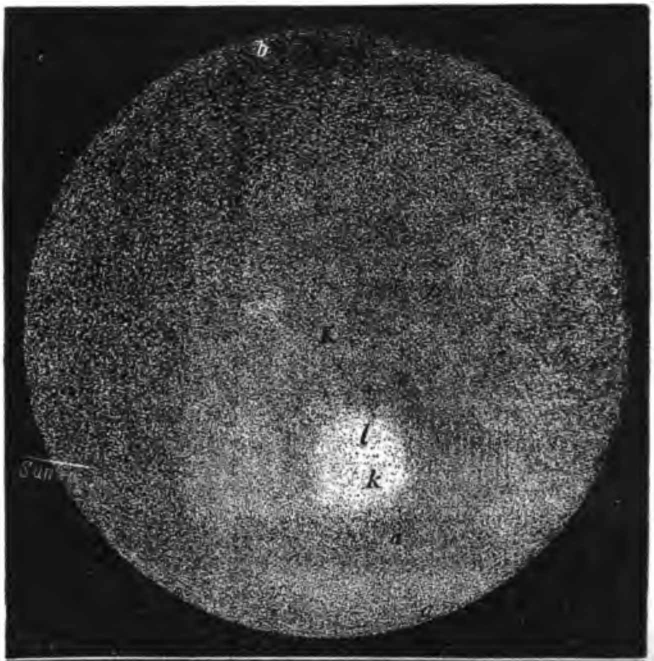
87. The expectation so generally entertained, that, on the occasion of its return to perihelion in 1835, this comet would afford observers occasion for obtaining new data, for the foundation of some satisfactory views respecting the physical constitution of the class of which it is so striking an example, was not disappointed. It no sooner reappeared than phenomena began to be manifested, preceding and accompanying the gradual formation of the tail, the observation of which has been most justly regarded as forming a memorable epoch in astronomical history.

Happily, these strange and important appearances were observed with the greatest zeal, and delineated with the most elaborate and scrupulous fidelity by several eminent astronomers in both hemispheres. MM. Bessel at Konigsburg, Schwabe at Dessau, and Struve at Pultowa, and Sir J. Herschel and Mr. Maclear at the Cape of Good Hope, have severally published their observations, accompanied by numerous drawings, exhibiting the successive transformations presented under the physical influence of varying temperature, in its approach to and departure from the sun.

The comet first became visible as a small round nebula, without a tail, and having a bright point more intensely luminous than the rest eccentrically placed within it. On the 2nd October, the tail began to be formed, and, increasing rapidly, acquired a length of about 5° on the 5th; on the 20th it attained its greatest length, which was 20°. It began after that day to decrease, and its diminution was so rapid, that on the 29th it was reduced to 3°,

ENCKÉ'S COMET.

Fig. 7.—Encké's Comet, 1828, approaching the Sun; as it appeared 7th Nov., 1828. (Telescopic drawing by Struve.)



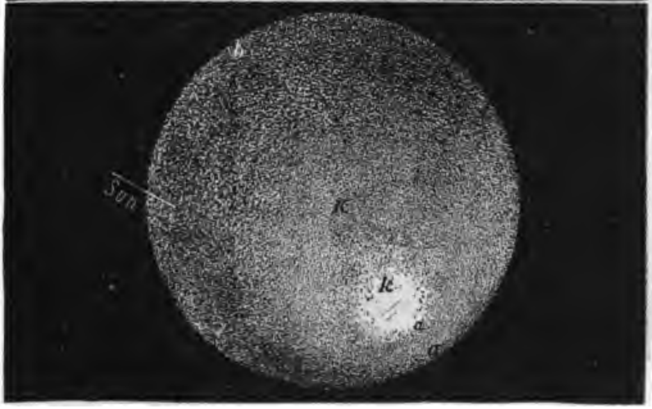


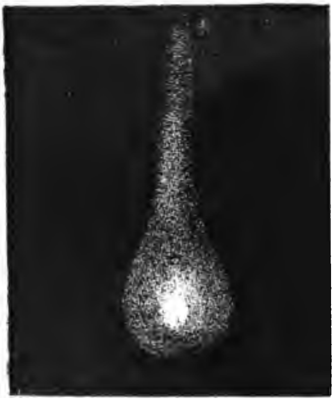
Fig. 8.—The same as it appeared 30th November, 1828.

and on the 5th of November, to 2½°. The comet was observed on the day of its perihelion by M. Struve, at the Observatory of Pultowa, when no tail whatever was apparent.

The circumstances which accompanied the increase of the tail from 2nd October, until its disappearance, were extremely remarkable, and were observed with scrupulous precision, simultaneously by Bessel at Konigsburg, by Struve at Pultowa, and by Schwabe at Dessau, all of whom made drawings from time to time, delineating the successive changes which it underwent.

On the 2nd, the commencement of the formation of the tail took place, by the appearance of a violent ejection of nebulous matter from that part of the comet which was presented towards the sun. This ejection was, however, neither uniform nor continuous. Like the fiery matter issuing from the crater of a volcano, it was thrown out at intervals. After the ejection, which was conspicuous, according to Bessel, on the 2nd, it ceased, and no efflux was observed for several days. About the 8th, however, it recommenced more violently than before, and assumed a new form. At this time Schwabe noticed an appearance which he denominates a "second tail," presented in a direction opposed to that of the original tail, and, therefore, towards the sun. This appearance seems, however, to be regarded by Bessel merely as the renewed ejection of nebulous matter which was afterwards turned back from the sun, as smoke would be by a current of air blowing from the sun in the direction of the original tail.

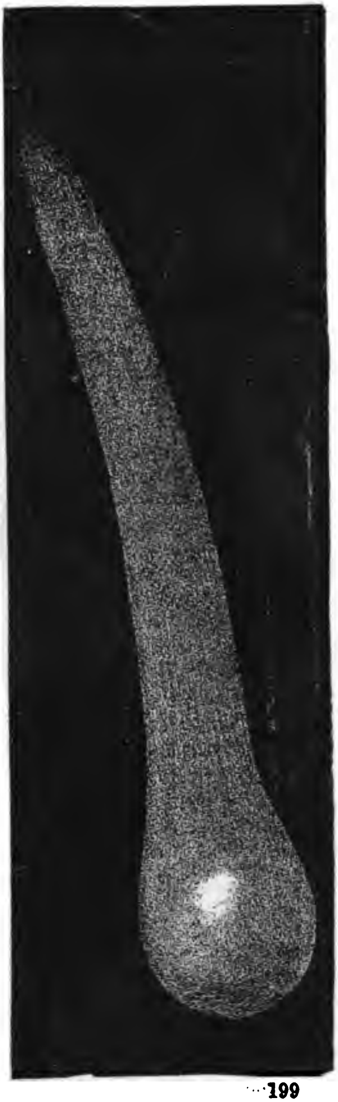
Fig. 9.—Sept. 29, 1835.



From the 8th to the 22nd, the form, position, and brightness of the nebulous emanations underwent various and irregular changes, the last alternately increasing and decreasing.

At one time two, at another three, nebulous emanations were observed to issue in divergent directions. These directions were continually varying, as well as their comparative brightness. Sometimes they would assume a swallow-tailed form, resembling the flame issuing from a fan gas-burner. The principal jet or tail was also observed to oscillate on the one side and the other of a line drawn from the sun through the centre of the head of the comet, exactly as a compass needle oscillates between the one and the other side of the magnetic meridian. This oscillation was so rapid, that the direction of the jets was visibly changed from hour to hour. The brightness of the matter composing them, being most intense at the point at which it seemed to be ejected from the nucleus, faded away as it expanded into the coma, curving backwards, in the direction of the principal tail, like steam or smoke before the wind.

Fig. 10.—Oct. 3, 1835.

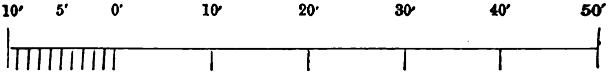


88. These curious phenomena will, however, be more clearly conceived by the aid of the admirable drawings of M. Struve, which we have reproduced with all practicable fidelity, in figs. 9, 10, 11, 12, 13, 14, 15, 16, 17, and 18. These drawings were executed by M. Kruger, an eminent artist, from the immediate observation of the appearances of the comet with the great Fraunhoffer telescope, at the Pultowa Observatory. The sketches of the artist were corrected by the astronomer, and only adopted definitively after repeated comparisons with the object. The original drawings are preserved in the library of the observatory.

89. Fig. 9 (page 198) represents the appearance of the comet on the 29th September. The tail was difficult to be recognised, appearing to be composed of very feeble nebulous matter. The nucleus passed

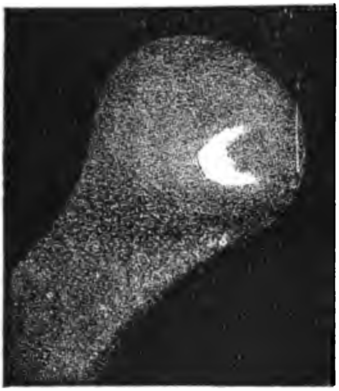
almost centrically over a star of the tenth magnitude, without in the slightest degree affecting its apparent brightness. The star was distinctly seen through the densest part of the comet. Another transit of a star took place with a like result.

Annexed is the scale according to which this drawing has been made.

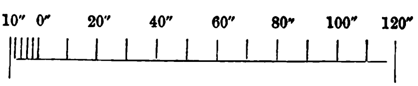


90. The comet changed not only its magnitude and form, but also its position, after September 29. On that day the direction of the tail was that of the parallel of declination through the head. On October 3rd it was inclined from that parallel towards the north at a small angle, and, instead of being straight, was curved, as shown in fig. 10 (page 199). The diameter of the head was increased in the ratio of 2 to 3, and the length of the tail in the ratio of nearly 1 to 3.

Fig. 11.—Oct. 8, 1835.



91. On the 5th, 6th, and 7th the comet underwent several changes: the nucleus became more conspicuous. On the 6th, a fan-formed flame issued from it, which disappeared on the 7th, and re-appeared on the 8th with increased splendour, as represented in fig. 11, which is drawn on the subjoined scale:

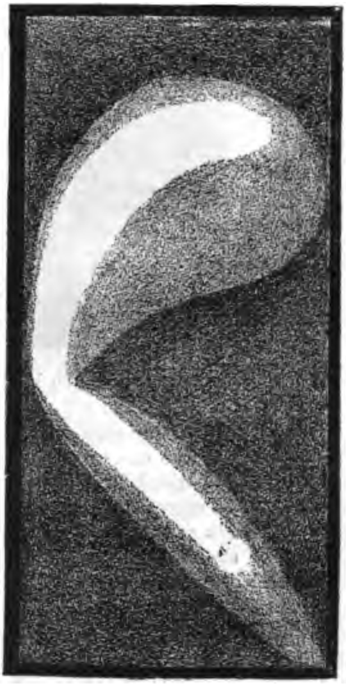


The nucleus appeared like a burning coal of oblong form, and yellowish colour. The extent of the flame-like emanation was about 30″. The feeble nebula surrounding the nuclei extended much beyond the limits of the drawing, but, being overpowered by the moonlight, could not be measured.

92. The comet as it appeared on the following night is shown in fig. 12, which is on the same scale as fig. 11. The nucleus and flame-like emanation entirely changed their form and magnitude

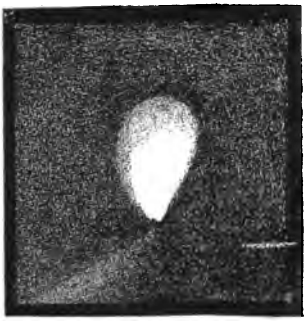
since the preceding night. The tail (not included in the drawing) measured very nearly 2°. The flame consisted of two parts, one resembling that seen on the 8th, and the other issuing like the jet from a blow-pipe in a direction at right angles to it. The figure represents the nucleus and flame as they appeared at 21^h sidereal time, with a magnifying power of 254.

Fig. 12.—Oct. 9, 1835.



93. The appearance of the following night is shown on the same scale in fig. 13. The tail, which still measured nearly 2°, was now much brighter, being visible to the naked eye, notwithstanding strong moonlight. The coma was evidently broader than the tail. The flaming nucleus is represented in the drawing as it appeared under a magnifying power of 86, with a field of 18′ diameter, the entire of which was filled with this coma. The diameter of the latter must, therefore, have been more than 18′. The drawing was taken at 21^h. s. t.

Fig. 13.—Oct. 10, 1835.



94. The comet is represented in fig. 14 (page 202), on the same scale, as it appeared on the night of the 12th. It appeared at 0^h 25^m s. t. for a short interval in uncommon splendour, the nucleus and flame, however, alone being visible, as represented in the drawing. The greatest extent of the flame measured 64″·7. Its appearance was most beautiful,

resembling a jet streaming out from the nucleus, like flame from a blow-pipe, or the flame from the discharge of a mortar, attended with the white smoke driven before the wind.

Fig. 14.—Oct. 12, 1835.

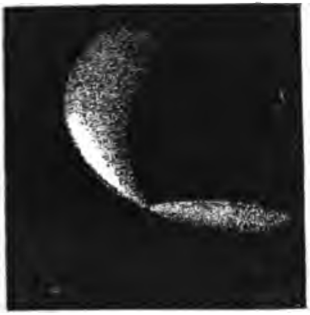
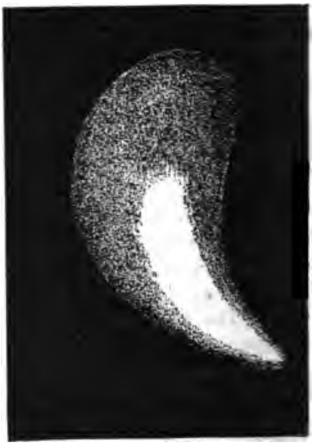
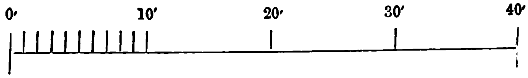


Fig. 15.—Oct. 14, 1835.

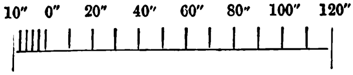


95. Its appearance on the 14th is shown, on the same scale, in fig. 15. The principal flame was now greatly enlarged, extending to the apparent length of 134″. Its deflection and curved form were most remarkable.

96. A cloudy sky prevented all observation for 12 days. On the 27th, the comet appeared to the naked eye as bright as a star of the third magnitude, the tail being distinctly visible. The coma surrounding the nucleus appeared as a uniform nebula. The tail was curved and of great length; but, owing to the low altitude at which the observation was taken, it could not be measured. On the 29th, however, the comet was presented under much more favourable conditions, and the drawings, fig. 16 and fig. 17 were made. The former represents the entire comet, including the whole visible extent of the tail, and is drawn to the annexed scale of minutes.



The latter represents the head of the comet only, and is drawn to the annexed scale of seconds.

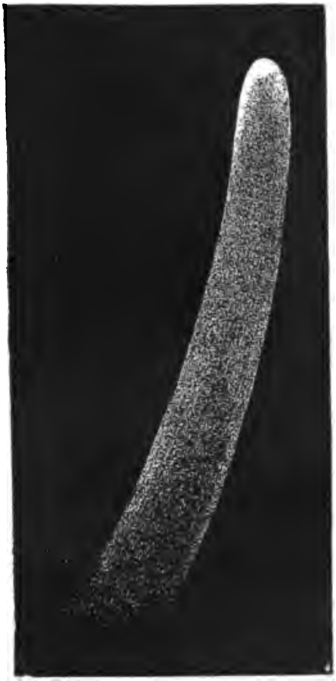


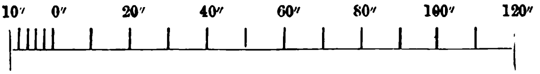
At 20^h 30^m s. t., the head presented the appearance represented in fig. 17 (page 204). The chief coma was almost exactly circular, and had a diameter of 165″. With a power of 198, the nucleus appeared as in the figure, the diameter being about 1″·25 to 1″·50. The flame issuing from the nucleus, curved back like smoke before the wind, was very conspicuous. The appearance of the formation of the tail as it issues from the nucleus was remarkably developed.

97. On the 5th of November the comet appeared as shown in fig. 18 (page 204). This drawing represents the nucleus and flame issuing from it on the scale of seconds given below.

The proper nucleus was found to measure about 2″·3. Two flames were seen issuing from it in nearly opposite directions, and both curved towards the same side. The brighter flame, directed towards the north, was marked by strongly defined edges. The other, directed towards the south, was more feeble and ill-defined.

Fig. 16.—Oct. 29, 1835.





98. Sir J. Herschel, who also observed this comet himself at the Cape of Good Hope, makes from all these observations the following inferences.

(1.) That the matter of the comet vaporised by the sun's heat escapes in jets, throwing the comet into irregular motion by its reaction, and thus changing its own direction of ejection.

(2.) That this ejection takes place principally from the part presented to the sun.

(3.) That thus ejected it encounters a resistance from some

Fig. 17.—Oct. 29, 1835.

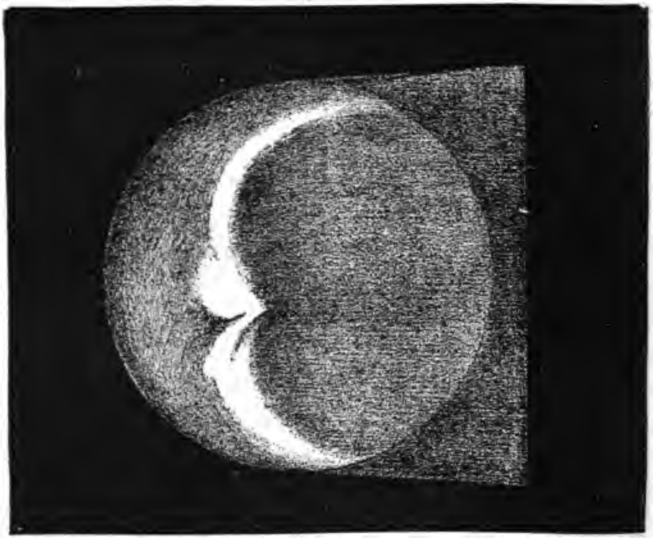
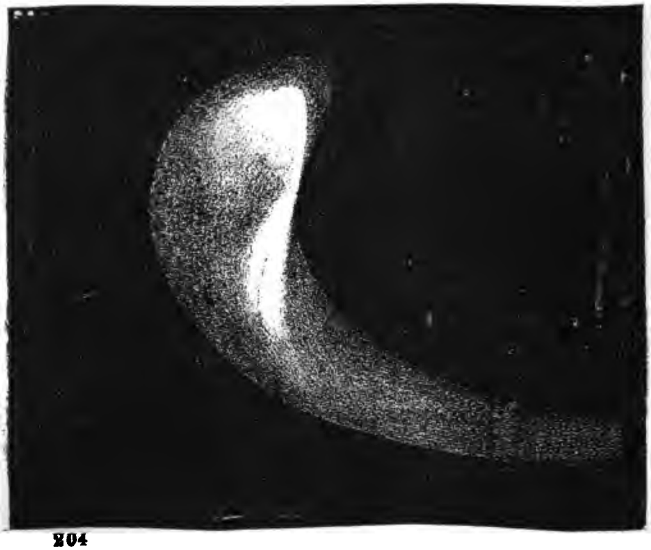


Fig. 18.—Nov. 5, 1835.



unknown force by which it is repulsed in the opposite direction, and so forms the tail.

(4.) That this acts unequally on the cometary matter, which is not all vaporised, and of that which is, a considerable portion is retained, so as to form the head and coma.

(5.) That this force cannot be solar gravitation, being contrary to that in its direction, and very much greater in its intensity, as is manifest by the enormous velocity with which the matter of the tail is driven from the sun.

(6.) That the matter thus repelled to a distance so great from a body whose mass is so small must, to a great extent, escape from the feeble influence of the gravitation of the mass composing the head and coma, and, unless there be some more active agency in operation, a large portion of such vaporised matter must be lost in space, never to reunite with the comet. This would lead to the consequence, that at every passage through its perihelion the comet would lose more and more of its vaporisable constituents, on which the production of the coma and tail depends, so that, at each successive return, the dimensions of these appendages would be less and less, as they have in fact been found to be.

99. On receding from the sun after its perihelion, the comet was observed under very favourable circumstances at the Cape by Sir J. Herschel and Mr. Maclear. It first reappeared there on the 24th of January, under an aspect altogether different from that under which it was seen before its perihelion. It had evidently, as Sir J. Herschel thinks, undergone some great physical change, which had operated an entire transformation upon it.

"Nothing could be more surprising than the total change which had taken place in it since October. . . . A new and unexpected phenomenon had developed itself, quite unique in the history of comets. Within the well-defined head, somewhat eccentrically placed, was a vivid nucleus resembling a miniature comet, with a head and tail of its own, perfectly distinct from and considerably exceeding in intensity the nebulous disc or envelope which I have above called the 'head.' A minute bright point, like a small star, was distinctly perceived within it, but which was never quite so well defined as to give the positive assurance of the existence of a solid sphere, much less could any phase be discerned."*

100. The phenomena and changes which the comet presented from its reappearance on the 24th of January, until its final

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* "Cape Observations," p. 397.

disappearance, have been described with great clearness by Mr. Maclear, and illustrated by a beautiful series of drawings by that astronomer and his assistant, Mr. Smith, in a memoir which appeared in the tenth volume of the Transactions of the Royal Astronomical Society, from which we reproduce the series of illustrations given in fig. 19 to fig. 29.

101. On the night of the 24th of January, 1836, the comet appeared, as in fig. 19, visible to the naked eye as a star of the second magnitude. The head was nearly circular, and presented a pretty well-defined planetary disc, encompassed by a coma or halo of delicate gossamer-like brightness. The diameter of the head, without the halo or coma, measured 131″, and with the latter 492″.

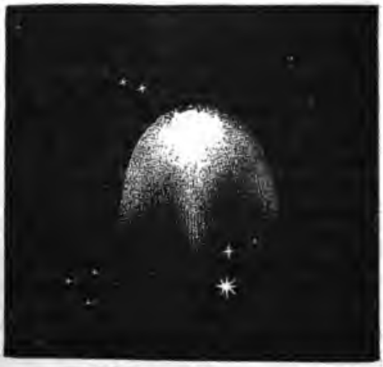
102. On the night of the 25th the comet had the appearance represented in fig. 20. The circular form was broken, and the magnitude of the head was increased. Three stars were seen through the coma and one through the head.

103. On the 26th of January the magnitude of the head was further increased, but that of the coma was diminished (fig. 21).

104. On the 27th the comet began to assume a parabolic form, as shown in fig. 22, and the increasing magnitude continued.

105. On the 28th the coma or halo was quite invisible, but the nucleus appeared like a faint small star. The magnitude of the comet continued to increase. The observer fancied he saw the faint outline of a tail (fig. 23).

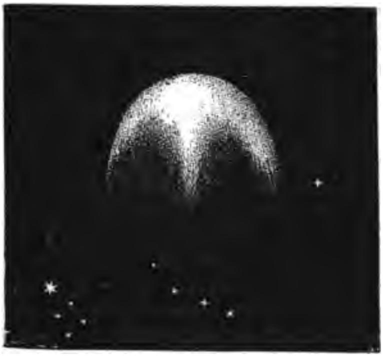
Fig. 23.—January 28, 1836.



106. On the 30th the form of the comet became decidedly parabolic (fig. 24). The breadth across the head was 702″, being greater than on the 24th in the ratio of 49 to 70, or 7 to 10,

which corresponds to an increase of volume in the ratio of 1 to 3, supposing the form to remain unchanged; but it was estimated

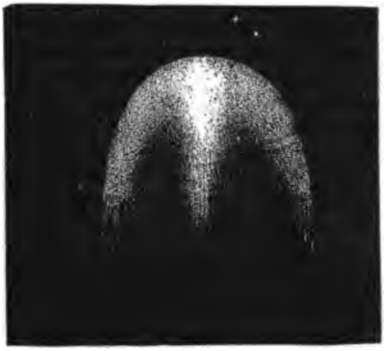
Fig. 24.—January 30, 1836.



that the extension in length gave a superficial increase in the ratio of 35 to 1, which would correspond to a much greater augmentation of volume.

107. On the 1st of February a further increase of magnitude took place, the figure remaining the same (fig. 25).

Fig. 25.—February 1, 1836.



108. On the 7th of February the comet was rendered faint by the effect of moonlight (fig. 26).

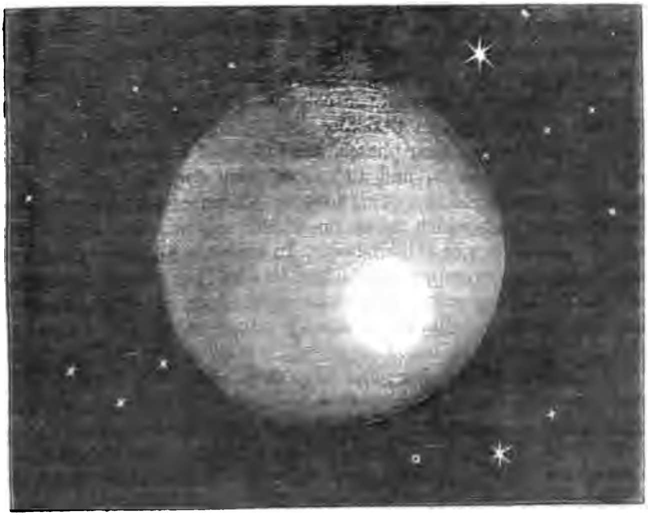
109. On the 10th a further increase of volume took place, a star being visible through the body (fig. 27).

110. From the 16th, on which it presented the appearance shown in fig. 28, to the 23rd, when it assumed the appearance shown in fig. 29, the magnitude went on increasing, while the illumination became more and more faint, and this continued until the comet's final disappearance; the outline, after a short time, became so faint as to be lost in the surrounding darkness, leaving a bland nebulous blotch with a bright centre enveloping the nucleus.

111. According to Mr. Hind, the number of comets which have appeared since the birth of Christ in each successive century is as follows: first century, 22; second, 23; third, 44; fourth, 27; fifth, 16; sixth, 25; seventh, 22; eighth, 16; ninth, 42; tenth, 26; eleventh, 36; twelfth, 26; thirteenth, 26; fourteenth, 29; fifteenth, 27; sixteenth, 31; seventeenth, 25; eighteenth, 64; nineteenth (first half), 80. Total, 607.

112. Since comets are visible only near their perihelia, when their velocity is greatest, the duration of their visibility at any single perihelion passage is generally short. The longest appearance on record is that of the great comet of 1811 (No. 8, Table VI., "Hand-Book of Astronomy," chap. xviii.), which continued to be visible for 510 days. The comet of 1825 (No. 2, Table VI. "Hand-Book of Astronomy," chap. xviii.) was visible for twelve months, and others which appeared since have been seen for eight months. In general, however, these bodies do not continue to be seen for more than two or three months.

113. Considering the vast number of comets which have passed through the system, such an incident as the collision of one of them with a planet might seem no very improbable contingency. Lexell's comet was supposed to have passed among the satellites of Jupiter; and, if that was the case, it is certain that the motions of these bodies were not in the least affected by it. The nearest approach to the earth ever made by a comet was that of the comet of 1684 (No. 55, Table VIII., "Hand-Book of Astronomy," chap. xviii.), which came within 216 semidiameters of the earth, a distance not so much as four times that of the moon. We are not aware of any nearer approach than this being certainly ascertained.



TELESCOPIC VIEW OF ENCKE'S COMET, BY STRUVE, AS IT APPEARED ON NOV. 7, 1828.

COMETARY INFLUENCES.

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CHAPTER I.

1. Popular tendency to connect terrestrial events with celestial phenomena. —2. Popular opinions as to influences of Comets.—3. Explanation of Comets, their nature — attractions — their shape, volume, and mass — tails — density—non-luminous.—4. Question discussed as to a Comet encountering the Earth, and the result — Comet of 1832, of 1805—Probabilities of such an occurrence.—5. Question discussed as to the temperature of the seasons being affected by Comets.—6. Question discussed as to the Earth passing through the tail of a Comet, and the probable consequences.—7. Suppositions adopted by some authors as to Comets producing epidemic diseases—Comet of 1680—Great Plague of London—Comet of 1668 alleged to have produced a remarkable epidemic among cats in Westphalia.—8. Comet of 1746—Earthquakes of Lima and Callao ascribed to it.—9. Various influences ascribed to particular Comets—Earthquakes—Plagues—the success of the Turks under Mahommed II.

1. In all ages, and among all people, a tendency has prevailed to connect terrestrial events with celestial phenomena. Popular opinion in such cases seeks no reason for its foundation. No attempt to establish any such relation as that of cause and effect

is thought of. The appearance presented in the heavens, whatever it be, is simply regarded as the harbinger, precursor, or presage of the terrestrial events which are supposed to accompany or to succeed it. When the celestial phenomena thus regarded are from their nature periodical and recurring, as in the case of the succession of lunar phases, some attempt is made to generalise the imputed effects, and to reduce them to rules. In the case, however, of celestial appearances, which are occasional and extraordinary, and which have no discovered periodicity, no such general rule can be established. In such cases mankind is, however, not less prompt and confident in ascribing to their appearance any extraordinary events whatever which may have taken place simultaneously with or immediately after them.

2. Among this latter class of occasional phenomena comets hold a conspicuous place, and have at all times and in all countries operated powerfully on the superstitious feelings of mankind. These bodies, scarcely less in modern and enlightened times than in the more remote and darker ages, and scarcely less among the most civilised than among the most barbarous nations, have been regarded with feelings of inexpressible awe and terror, and looked upon as the harbingers and precursors of the most extraordinary diversity of effects, physical, physiological, social, and political. To them are unhesitatingly ascribed extraordinary extremes of heat and cold of the seasons, whether general or local; storms of snow, hail, wind and rain, hurricanes, earthquakes, volcanic eruptions, floods, droughts, and fogs; every form and character of epidemic malady, whether affecting the human race or the lower animals, the state of the harvest and the vintage, whether it be that of scarcity or abundance, of good or bad quality; the fruitfulness of women, the births and deaths of extraordinary men, the march of armies, and the fall of empires.

3. Without insisting, as we very well might, upon the manifest absurdity and glaring contradiction and inconsistency of most of these supposed influences or effects, let us first explain briefly, so far as observation has informed us, what the bodies are, to which effects so diverse and extraordinary are imputed. Such an explanation will of itself go far to dispel most of these errors. We shall also compare the effects ascribed to the presence and influence of comets with the dates of the appearances of these bodies, their number, magnitude, and proximity, so as to ascertain whether any such correspondence has really existed as has been assumed.

Comets are not, as was anciently supposed, atmospheric phenomena. They move through the regions of space occupied by the planets. Most of them come into the solar system from parts of the universe which extend to enormous distances beyond its limits, and after passing among the planets and approaching more or less near to the sun, they again disappear, issuing to distances not less remote.

The number of those which have been actually seen, and whose appearances have been recorded, amounts to many hundreds. But when the chances against these bodies being visible during the intervals, often very brief, of their passage through the solar system, the vast numbers of them which can only be seen by the aid of telescopes, the frequency of their position being such that they are only above the horizon of observers during the day, or that they can only be within the range of vision in latitudes where no observers are found, are severally considered, it will be evident that the number of comets actually seen must form a very small fraction of the total number which have visited our system.

Reasoning upon the common principles of the doctrine of probabilities, Arago has shown that the number of comets which have passed through the system cannot be less than three and a half millions, but that it is possible that they may amount to twice that number. Even with the limited information respecting these bodies, which was attainable by Kepler, that astronomer declared that "there are more comets in space than fishes in the ocean."

Of the many hundreds whose appearances have been recorded, dating from the earliest historical notices of these bodies, about two hundred have been observed during the short intervals of their appearance, with sufficient precision to enable astronomers to calculate the paths or orbits in which they moved. These calculations have led to a result of the highest importance, inasmuch as they have established demonstratively the fact that these comets are masses of ponderable matter. The forms of their orbits prove this. It has been shown by Newton that if a body move in a certain form of curve, called by geometers a conic section, having a point called its focus at the centre of the sun, it must be subject to the attraction of the sun's gravitation, and it must reciprocally attract the sun. Now these comets have been ascertained by observation to move in these very curves, the sun being in their common focus. Hence they and the sun mutually attract each other, according to the universal law of gravitation. They are, therefore, masses of ponderable matter.

But these masses are not only attracted by the sun but by the planets, primary and secondary, near to which they pass, and they are ascertained to deviate considerably, by reason of such attractions, from the paths they would follow if subject only to the sun's attractive force. Now, by the general law of gravitation, that attraction is always reciprocal, and it is certain that the comets attract the planets as strongly as the planets attract them, and if the masses of the comets were as great as those of the planets, they would cause the planets to deviate from their accustomed path as widely as the planets cause them to deviate. If, however, we find, that while the deviation of the comets, in virtue of this mutual attraction, is very great, that of the planets is extremely small, the inference must be that the masses of the comets are smaller than those of the planets, in exactly the proportion in which the effect of the attraction on the planet is less than its effect upon the comet.

Now, in fact, it has been found that while the deviation of the comets, due to the attractions of the planets, is very considerable, that of the planets, of the satellites, and even of the planetoids (the smallest bodies of the solar system), is so minute as to be absolutely inappreciable by the most exact means of observation. A case is even recorded in which a comet passed almost in contact with the satellites of Jupiter, if, indeed, it did not pass among these small bodies, yet its attraction upon them was so feeble as to produce not the slightest observable effect upon their motions, although the comet itself, by the attraction of the planet, was so strongly affected that its orbit was completely changed.

By such observations and calculations it has then been established that, although the comets are masses of ponderable matter, the quantity of matter composing each of them is incalculably less than that of the smallest planet, primary or secondary, of the solar system.

These bodies are as remarkable for the vastness of their magnitude, and the strangeness, variety, and mutability of their forms as for the smallness of their masses.

Comets in general, and more especially those which are visible without a telescope, present the appearance of a roundish mass of illuminated vapour or nebulous matter, to which is often, though not always, attached a train more or less extensive, composed of matter having a like appearance. The former is called the HEAD, and the latter the TAIL of the comet.

The tail is more significantly called the *brush* by Chinese astronomers.

The illumination of the head is not generally uniform. Sometimes a bright central spot is seen in the nebulous matter which forms it. This is called the NUCLEUS.

The nucleus sometimes appears as a bright stellar point, and sometimes presents the appearance of a planetary disk seen through a nebulous haze. In general, however, on examining the object with high optical power, these appearances are changed, and the object seems to be a mere mass of illuminated vapour from its borders to its centre.

The nebulous haze which always surrounds the nucleus is called the COMA.

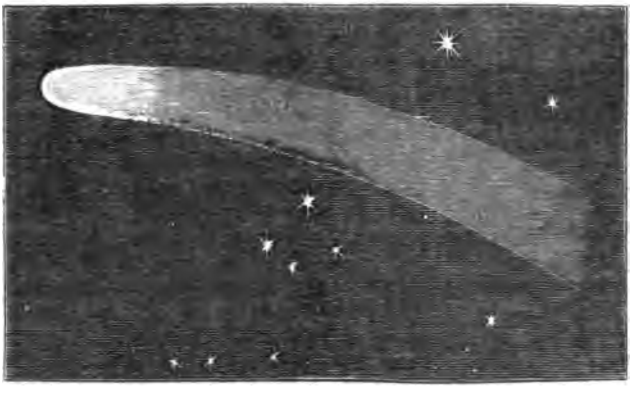
These terms COMA and COMET are taken from the Greek word κομή (komé) hair, the nebulous matter composing the coma and tail being supposed to resemble hair, and the object being therefore called κομήτης (kometes), a hairy star.

A telescopic view of one of the globular comets without a tail is given at the head of this chapter. This is the comet known as Encke's comet, so called from the astronomer who calculated its orbit.

This may be taken as a general representation of the apparent form of the comets without tails. The real form is evidently globular or spheroidal.

The comets with tails are infinitely various in form. In fig. 2 is represented the comet known as Halley's Comet, as it appeared on the 3rd October, 1835; and this may also be taken as a very general representation of comets with tails.

Fig. 2.



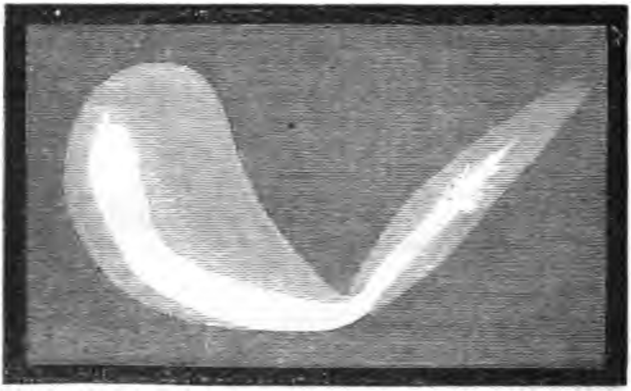
The rapidly changing and capricious forms of these singular bodies may be conceived from fig. 3, p. 70, which represents the same comet as it appeared on the 9th October; and the figure at the head of Chapter II. as it appeared on the 5th November.

Nothing which attends these extraordinary objects is more astonishing than their prodigious dimensions. The head of the great comet which appeared in 1811 was a globular mass, whose diameter measured 1,250000 miles. Its bulk must, therefore, have been thrice that of the sun, and *nearly four million times that of the earth!* But astounding as this is, the dimensions of the tail were still more so. The length of that vast appendage was an hundred and thirty millions of miles, so that if the head were at the sun, the tail would extend to thirty millions of miles beyond the earth!

Supposing this tail to consist of continuous matter, let us see what its quantity must be by measure. Its diameter at the point where it emanated from the head was equal to that of the head, but as its sides were slightly divergent, its diameter increased as the distance from the head increased; but let us take it as equal only to the diameter of the head.

The length of the tail having been an hundred and thirty millions of miles, while the diameter of the head was a million and a quarter of miles, it will follow that the length of the tail was 104 times the diameter of the head. If the sides of the tail, instead of being divergent, were parallel, it would thence follow, by the principles of geometry, that the volume or cubical bulk of the tail must have been an hundred and fifty times greater than that of the head, and since the bulk of the head was four million times that of the earth, that of the tail and head together (without taking into account the effect of the divergence of the tail), must have been *nearly six hundred million times the bulk of the earth!!*

Fig. 8.



It must be observed, however, that some appearances observed in the tails of comets have suggested to astronomers the probability that they may be hollow, that is to say, that instead of being cylindrical or conical columns of vaporous matter, they are thin cylindrical or conical *tubes* of vapour, like the funnel or pipe of a stove. In that case, of course, the bulk or volume of vaporous matter entering into their composition would be much less than we have here computed, but the actual volume included within their limits would still be the same.

In form the tails are sometimes straight, and sometimes curved like a scymeter, as represented in fig. 2. When the great comet of 1456 appeared it had that form; and in the superstitious spirit of that age, it was regarded as a celestial sign of the success of the Turkish invasion of Europe, from its resemblance to a Turkish sabre.

The tail is not always single. Comets have appeared with two or more tails. In 1744 a comet appeared with six tails, each of which was curved nearly to the form of a quadrant.

The magnitude of these enormous appendages is even less amazing than the brief period in which they are sometimes thrown out from the head. The great comet of 1843 had a tail which measured two hundred millions of miles, so that if the head were at the sun, the tail would extend to an hundred millions of miles beyond the earth. Yet this tail was thrown out in less than twenty days. If, as we must suppose, it was wholly composed of matter issuing from the head, with what inconceivable force must not the matter have been ejected which formed the extremity of the tail! The matter having been driven through two hundred millions of miles in twenty days, must have had a velocity of ten millions of miles per day. This would be at the rate of above four hundred thousand miles per hour, seven thousand miles per minute, or an hundred and fifteen miles per second.

This velocity is nearly six times that of the earth in its orbit, and is two hundred and fifty times greater than that of a cannon ball.

It may be easily imagined that the matter to which such a velocity could be imparted by the reaction of such a body as the comet (itself, according to all probability, consisting of mere vapour), must be infinitely attenuated.

But there are other proofs how light and rarified must be the matter composing these bodies.

Since the masses of comets are so infinitely minute, while their volumes are so prodigious, it must follow that the density of the matter composing them is exceedingly small, so small indeed, that they must be, bulk for bulk, immeasurably lighter than air or the most expansive vapour. Other appearances attending them are also consistent with this. Thus it has been found that the smallest stars—stars so minute as to be barely visible by the aid of powerful telescopes, have been distinctly seen, and seen without any perceptible diminution of their lustre, through the very centre of the head of these bodies. It would follow, therefore, that the matter composing them is so attenuated that a thickness of so many thousand miles of it has no sensible imperfection of transparency.

There is, therefore, the strongest reason to conclude that the material of which comets are composed is vaporous or aëriform, and that it is in the most attenuated state that can well be imagined, being probably some thousand times less dense than our atmosphere.

It has also been ascertained on satisfactory grounds that this matter is not luminous, but, like the clouds which float in our atmosphere, is illuminated by the sun, and thus rendered visible. Some circumstances attending the variation of the magnitude of the visible material of these bodies also render it probable that they are composed of vapour, which when raised to a certain temperature by their proximity to the sun, becomes absolutely transparent and invisible, and which as the comet recedes from the centre of light and heat is gradually condensed and becomes visible, just as steam issuing from the safety-valve of a boiler is, at the moment of its escape and before its condensation, transparent and invisible, and assumes a greater and greater volume of whitish cloudy matter, as its distance from the valve and its exposure to the condensing effect of the cold air increases. In this way is explained the fact, that comets in general are augmented in their visible volume as they recede from the sun.

Such then being generally the nature and character of these bodies, so far as observation has enabled astronomers to determine them, it remains to inquire how far there are any grounds for the various effects and influences which have been ascribed to them.

4. Of all the effects which have been ascribed to comets, that of a collision with the earth is perhaps the least unreasonable.

That such an event is *possible*, cannot be denied. It remains, therefore, only to estimate its probability, and the effects it might produce if it occurred.

That a comet should encounter a planet, two conditions must evidently be fulfilled:—1st, the path of the comet must intersect that of the planet; and, 2nd, the two bodies must arrive at the same time at this point of intersection.

Now, of all the known comets there is not one of which the orbit intersects the orbit of any planet. There is, however, one whose orbit passes so near the earth's orbit, that the distance between the two points where they are nearest is less than the semi-diameter of the comet, and it follows, consequently, that if the earth and comet were to arrive together at these points, the earth must pass through the comet. If the comet were solid, which it is not, a collision must take place. But being composed of the lightest and most attenuated vaporous matter, the effect would be the same as if the earth were to pass through a very thin cloud.

This particular comet happens to be one of the few which have been ascertained to revolve round the sun in a definite period like the planets, with this difference, however, that the orbit is a somewhat elongated oval instead of one which is nearly circular. The period of this comet being about six years and three quarters, it follows that it must pass through the place of danger to the earth once in that interval.

It passed through that place in 1832, under circumstances which excited among the world in general, who were taught to expect its approach, and to know its proximity to the earth's path, a certain panic of apprehension as to the possible consequences. These fears were however groundless, for the comet passed through the point of danger on the 29th October, and the earth did not arrive at that point until the 30th November. Now, since the earth moves at the rate of above a million and a half of miles per day, it follows that on the 29th October, the day on which the comet passed through the point of danger, the earth must have been nearly fifty millions of miles from that point.

In 1805, the same comet passed through the same point, under circumstances which, had they been as generally known as in 1832, might have more reasonably excited apprehension, for in that case the distance of the earth from the comet was only five millions of miles.

It may, nevertheless, be observed with truth, that although the danger of an encounter with the comets whose orbits are known, be insignificant, the risk with relation to the far more numerous class of these bodies, whose motions are unascertained and which pass continually among the planets may be much greater.

Nothing, however, is more easy than to apply to this question the well understood principles of the theory of probabilities, assuming such conditions respecting the number and magnitude of the comets, as all must admit to be the most favourable imaginable to the catastrophe of collision. This has been accordingly done. It has been shown that, assuming the number of comets which pass within the earth's orbit to be the greatest that it can be imagined to be, and that the magnitudes of these comets be also the greatest that they can be conceived to be, the chances against a collision of the earth with any individual comet would be 281 millions to one.

Let us illustrate the meaning of this arithmetical conclusion. If a comet appear next month, and if such a comet, encountering the earth, would destroy the whole human race by the shock, how is the danger of such a catastrophe, as it affects each individual, to be estimated? We answer that this danger would be exactly the same as if 281 millions of white balls and one black ball were put into an urn, and that the death of the individual was to be the consequence of the single black ball being drawn from the urn by the hand of a blind man.

This conclusion, which is based upon strict mathematical reasoning, will, we presume, be sufficient to reassure the most timid and sensitive as to the danger of the collision of the earth with a comet.

5. Popular opinion is universal and emphatical in all countries that comets influence the temperature of the seasons, and although popular opinion is not always infallible, it is not to be lightly rejected.

All the world knows that the excellence of the celebrated vintage of 1811 was by common consent ascribed to the influence of the splendid comet which appeared in that year. The "wine of the comet" was long known, and bore a high price in the market. The abundant harvest of the same year was ascribed unanimously to the same cause.

An article appeared in the "Gentleman's Magazine," in 1818, upon the supposed influences of the comet of 1811, in which it was affirmed that, although the winter was mild, the spring humid, and the summer cold, the sun scarcely appearing with force sufficient to ripen the fruits of the earth, yet such was the effect of the comet that the grain harvest was exceptionally abundant, and certain sorts of fruits, such as melons and figs, were not only produced in unusual quantity, but had a delicious flavour. It was further observed wasps were few; that flies became blind, and disappeared early, and that the frequency with which women produced twins was especially remarkable! It even happened that the wife of a shoemaker at Whitechapel had four children at a birth!! and all these marvellous effects were ascribed to the comet.

As to the question of the influence of comets on the temperature of the seasons, it is one of the most simple and most easy of solution. In all observatories, the appearances and motions of the comets are recorded. The average daily and monthly and yearly temperatures of the weather are also exactly observed and recorded. To ascertain, then, whether the comets really exercise any influence on the temperature of the seasons, it is only necessary to place in juxta-position the comets and the temperatures, and to examine whether there be any correspondence between them.

This was accordingly done by M. Arago. The records of the public observatories supplied the data necessary to make the comparison during the century which ended with 1832, and the result was that no correspondence whatever was discoverable. Sometimes it happened that the years of greatest mean temperature were those in which several comets appeared; in some they were those in which none appeared. In some cases the years signalised by the most remarkable comets were characterised by a high, in some by a low mean temperature. Thus in 1737, when two comets appeared, the temperature was lower than in the two preceding years when none appeared. Of the twenty years which commenced in 1763, the coldest, 1766, was that in which two comets, one of which was remarkable for its splendour, appeared. In an interval of 16 years, the warmest was 1794, in which no comet appeared, and the coldest was 1799, in which two were seen.

But omitting further notice of the thermal character of particular seasons, let us see what was the general result of this investigation. Of 74 years, 49 were signalised by the appearance of one or several comets, and 25 by their non-appearance. The mean temperature of the former years was found to be 51.°6, and that of the latter 50.°7, the difference being less than one degree.

Again, of the 49 years in which comets appeared, a single comet was seen in 25, and two or more comets in 24. If these bodies produced any influence on the temperature, a difference ought to be expected between the mean temperature of the latter and the former years. It was found, however, that the mean temperature of 25 years of a single comet was 51.°6, while that of the 24 years of several comets was 51.°4, the difference being only the fifth of a degree, and even that being *against* the influence of the comets in augmenting the temperature.

In fine, the complete discussion of the cometary and thermal observations, continued through an entire century, fully establishes the conclusion that there exists no foundation whatever for the popular opinion that the comets influence the seasons.

6. Of all the eventualities which may arise out of the motion of comets through the system, the least improbable and moreover that of which the consequences are most difficult to foresee, is the passage of the earth through the tail of one of these bodies.

The comets are exceedingly numerous; but few of them have tails. These appendages where they exist are generally of very limited length, but in some rare instances, as has been already stated, their length is prodigious, extending over a space not less than the thirtieth part of the extreme diameter of the solar system. If such a comet had its head at the surface of the sun and its tail in the plane of the ecliptic, the tail would sweep over the space through which the planets, Mercury, Venus, the Earth and Mars move, and it might in that case encounter any or all of these planets.

It cannot, therefore, be denied that the immersion of the earth in the tail of a comet is a possible event. That it is extremely improbable, however, may be shown by the same reasoning as has been already stated in reference to the question of the probability of the collision of a comet and the earth, combined with the consideration that very few comets have tails of considerable length.

But, supposing such an event to take place, what would be the probable consequences?

It is certain that the matter composing the tails of comets is of such a nature that although these appendages have often a thickness measuring many thousand miles, the smallest telescopic stars are visible through it, without the least perceptible diminution of their lustre.

The matter of the tail being, therefore, so completely transparent, and producing moreover no perceptible refraction, its density, if it be vaporous or aëriform, must be extremely inconsiderable, and according to all probability, many thousands of times less than the density of our atmosphere.

If such be its nature, when the earth would pass through it, it would mingle with the terrestrial atmosphere, and if its density were, for example, a thousand times less dense than the air, the atmosphere would contain one particle of cometic matter to every thousand particles of pure air.

Let us suppose that the room we inhabit contains 10,000 cubic feet of air, and let 10 cubit feet of any noxious gas be introduced into it and mixed with the air. We should then take into the lungs in respiration one particle of the noxious gas with every thousand particles of pure air. So far as the possible injurious effects depend on the numerical proportion of impurity, there would appear in such case to be but little ground of reasonable fear.

We have, however, numberless examples of the strong effect produced upon our organs by effluvia with which the air is occasionally impregnated, which, nevertheless, prevail in a proportion so minute as utterly to escape the nicest and most exact analysis.

A grain of musk, or a single drop of the otto of roses, will be sensible to the organ of smelling in a large room, and will continue to be sensible for a long period of time. The actual proportion, nevertheless, which the material effluvia producing this powerful effect upon the organs bears to the total quantity of air impregnated with it is quite inappreciable.

It is pretended by some medical practitioners that the effluvia inspired in smelling certain medicaments is capable of producing on patients the effects of an aperient, and it is well known that the effects of an emetic are often produced by certain odours.

Such analogies, therefore, show that the extreme state of attenuation, which probably characterises the tails of comets, does not necessarily exclude the possibility of their producing formidable effects upon the organised world, if they should be mingled with the atmosphere.

7. This supposition has accordingly been adopted by some authors, and among them not a few holding a position of authority in the world of science, as the means of explaining the prevalence, at various epochs, of epidemic diseases.

Gregory, in a work on Astronomy, published at Oxford in 1702, affirmed that, among all people and in all ages, the appearance of comets has been attended with such general effects; and he adds that it does not become philosophers to treat such traditions with levity, or to reject them, without consideration, as mere fictions.

So recently as 1829, Mr. T. Forster, an English medical practitioner, published a work, entitled "Illustrations of the Atmospherical Origin of Epidemic Diseases," in which he professed to prove that, since the Christian era, the periods which have been the most insalubrious have been invariably those at which some great comet was visible. He maintains that the malignant influence of these bodies is not limited to the human race, nor even to the organised world. He ascribes to them innumerable effects upon the inferior animals, and all the violent changes incidental to the atmosphere besides earthquakes, volcanic eruptions, floods, droughts, and famines.

Comets appear on the average at the rate of very nearly two per annum. Now, it is generally assumed by the partisans of their influence that they exercise these effects for some time before their appearance, and for some time after their disappearance. It cannot, therefore, be surprising that those who favour this theory should find a comet for every epidemic or other visitation, whether physical, or physiological, which they desire to ascribe to such a cause.

Nevertheless, frequent as are the appearances of these objects, and various as are the effects which the partisans of this theory are disposed to ascribe to them, cases have been presented in which the most ardent supporters of such a hypothesis are hard driven to find a misfortune or a malady to visit even upon the most formidable of the comets, and on the other hand, it is sometimes difficult to find a comet on which to saddle some of the greatest scourges which have visited our race.

One of the largest and most remarkable comets of modern times was that of 1680. It was also that which passed nearest to the sun, and not very far from the earth. Nevertheless the partisans of cometary influences have found it difficult to discover any calamity to visit upon that body. There were no epidemic diseases, local or general, to ascribe to it; but Mr. Forster assigns it as the cause of a cold winter, followed by a dry and warm summer, and some remarkable meteors seen in Germany!

The year of the great plague of London (1665) was signalised by a comet which appeared in the month of April, and to the influence of which that visitation was, of course, ascribed. No reasons, however, are given why London alone was obnoxious to this malign influence, and why no similar effect was produced in other European capitals, or even in other great towns of England, nor even in many of the villages with which London is begirt.

To this and all similar speculations it may be answered that, admitting the possible influence of comets, their effect ought to be general and not local. There can be no imaginable reason why such a body should affect, in a special manner, one particular spot upon the earth's surface, while the surrounding countries are exempt from the like consequences of its influence.

This is the conclusive answer to all the absurd speculations on cometary influences which fill the elaborate treatises of Gregory, Sydenham, Lubienetski, Forster, and others. Some of these effects appear so ludicrous that it is difficult to quote them in any serious discussion on a question of physical science.

A great comet appeared in the heavens in 1668, which there is some reason to suppose to be identical with the splendid object which passed through the system in 1843. One of the advocates of cometic influences discovered that the presence of this body in 1668 produced a remarkable epidemic among *cats in Westphalia!* We have not heard of any similar calamity in 1843.

8. A comet, not very conspicuous either for magnitude or brightness, passed near the earth in 1746. The destruction of the cities of Lima and Callao by an earthquake is imputed to this body, but no reason is assigned for the exemption of other cities of the South American continent.

9. To another comet is ascribed the destruction of a steeple-

clock in Scotland, by the fall of a meteoric stone; to another, the prevalence of flocks of wild pigeons in America; to another, remarkable eruptions of Etna and Vesuvius. The authors who, at great labour of research, rake together such incidents, make a vain display of erudition, and, as M. Arago wittily observed, are under a delusion similar to that of a lady mentioned by Bayle, who never looked out of the window of her apartment, situated in the greatest thoroughfare of Paris, and saw the street filled with carriages, without imagining that her appearance at the window was the cause of the crowd.

The celebrated traveller, Rüppel, writing from Cairo, on the 8th of October, 1825 (in which year three comets appeared), observed that "the Egyptians thought the comet then visible was the cause of the shocks of an earthquake which were felt in that country on the 21st of August, and that the same object exercised so malignant an influence on some of the lower animals, that horses and asses perished in great numbers. The truth was, that the poor animals died of starvation, the deficiency of the overflowings of the Nile having produced a scarcity of their forage."

"If I were not restrained by considerations of politeness," observed M. Arago, "I should find no difficulty in proving that, as far as respects astronomical information, there are other Egyptians beside those which are found on the banks of the Nile."

Physical effects are not the only influences imputed to comets. The comet now so familiarly known to the public as that of Halley, and whose last periodical re-appearance took place in 1835, appeared with extraordinary splendour in 1305, being described as "Cometa horrendœ magnitudinis visus est circà ferias paschatis, quem secuta est pestilentia maxima." Thus, as usual, the great plague was laid to the account of this body.

The next visit but one which the same comet paid to the solar system was in 1456, when it is represented as having an "unheard-of magnitude," and as having a tail which extended over sixty degrees of the heavens, being two-thirds of the distance from the zenith to the horizon. It was visible thus during the month of June, and spread terror throughout Europe. It was regarded as presaging the rapid success of the Turks under Mohammed II., who had taken Constantinople, advanced to the walls of Vienna, and struck terror into the whole Christian world. Pope Calixtus II., terrified for the fate of Christianity, directed the thunders of the Church against the enemies of the faith terrestrial and celestial, and in the same bull exorcised the Turks and the comet; and in order to perpetuate this manifestation of the power of the Church, he ordained that the bells should be rung at noon, a custom still observed in Catholic countries. Neither the progress of the comet, nor the victorious arms of the Mohammedans, were, however, arrested. The comet tranquilly proceeded in its orbit, passing through its appointed changes, regardless of the thunders of the Vatican, and the Turks established their principal mosque in the Church of St. Sophia.

A comet appeared in the year 590, to the presence and influence of which was ascribed a fearful epidemic, which prevailed in that year, in the crisis of which the patients were seized with violent paroxysms of sneezing, often followed by death. It became the custom, therefore, when these paroxysms manifested themselves, for the bystanders to address their benediction to the sufferer, exclaiming, "God bless you." This custom became permanent and universal, and to this day the sneezer is addressed in the same words.

TELESCOPIC VIEW OF HALLEY'S COMET ON 5TH NOVEMBER, 1835, BY STRUVE.

COMETARY INFLUENCES.

CHAPTER II.

10. The birth and death of heroes, &c.—11. Questions discussed as to whether the dry fog of 1783 or that of 1831 was produced by the immersion of the Earth in the tail of a Comet.—12. Influences of atmospheric disturbances and currents in producing extraordinary effects on epidemic diseases—The periodical wind called Harmattan from the interior of Africa.—13. Question discussed as to whether the Earth at any former epoch has been struck by the solid nucleus of a Comet—Its consequences.—14. Questions discussed as to whether the geographical condition of the Earth has ever been disturbed by the near approach of a Comet, and whether the Biblical Deluge can have been produced by such a cause.—15. Probability of the terrestrial equilibrium being injuriously deranged by near approach of a Comet reduced to nothing.—16. Opinions of Laplace.—17. Curious phenomena of Biela's comet.

10. As we go further back in history, the moral and political influences imputed to comets are multiplied in proportion to the darkness of these times. These objects have been supposed more especially to have portended the birth and the death of heroes. Thus a comet which appeared in 43 B.C., and which was stated to be so brilliant as to be visible to the naked eye in the day time,

was regarded by the Romans as the soul of Julius Cæsar (who was then recently murdered), transferred to the heavens.

A comet which appeared at the epoch of the birth of Mithridates, and another which was seen immediately before the birth of Mohammed, were each regarded as the portents of these historical celebrities.

A comet, supposed to have signalised the birth of Christ, was said to have appeared during an interval of twenty-four days, producing a light *surpassing that of the sun* (!), and with a magnitude which extended over a fourth part of the firmament, so as to occupy four hours in rising and setting.

The exaggeration of such statements must become glaringly apparent when it is considered that comets like planets and the moon derive all their light from the sun.

A comet appeared in March, 1402, the splendour of which is stated to have been so great, that it was visible at noon. A second appeared in the same year in June, which was so brilliant as to be visible for some hours before sunset. This comet was said to presage the death of John Galéas Visconti. That prince, being a believer in astrology, had consulted the charlatans of the day, and the fright produced by the appearance of the comet no doubt contributed to the fulfilment of the prediction.

Another conspicuous comet appeared in 1532, which was also stated to be visible before sunset. It produced much excitement in Northern Italy, where it was considered to presage the death of Sforza II.

11. It has been conjectured, not without some show of probability, that the great dry fogs which spread over a large portion of the surface of the earth in 1783 and 1831, were produced by the passage of the tail of a comet over the earth or over a part of it.

The great fog of 1783 had several characters which would entitle it to serious consideration in relation to this question. It commenced nearly on the same day (the 18th of June), at places very distant from each other, such as Paris, Avignon, Turin, and Padua. It covered a part of the earth's surface, extending north and south from Africa to Sweden. It prevailed on the North American as well as upon the European continent. It can scarcely, therefore, be denominated a local phenomenon in the ordinary use of that term.

It lasted for a month. That the atmosphere did not convey it over the regions in which it prevailed was proved by the fact that its position was not affected by the winds. Whatever direction the wind took, the position of the fog remained the same. It prevailed equally at all accessible heights above the surface. It was as dense upon the summits of the Alps as upon the plains of France.

The heavy and constant rains which fell in June and July, and the storms of wind which accompanied them, did not dissipate it.

Its density and partial opacity varied in different places. In Languedoc it was so dense, that the sun was not visible at altitudes below 12°; and at greater altitudes its light was red, and so subdued, that it could be looked at without inconvenience.

The quality by which it was distinguished from common fogs was its absolute dryness. Hygrometric instruments exposed in it indicated the complete absence of humidity.

One of the most remarkable circumstances, however, attending it was, that it appeared to be endowed with some faintly luminous quality, such as might be supposed to proceed from a slight degree of phosphorescence. Thus it appeared from the declarations of many observers that, while it prevailed at the epoch of new moon, and therefore in the total absence of moonlight, the light proceeding apparently from the fog was sufficient to render objects visible at distances of two or three hundred yards.

Such being the actual phenomena, it remains to be considered whether the hypothesis that the earth passed at that time through the tail of a comet can be admitted to explain them.

In the first place, it must be observed that the *head* of the comet, if such a body were present, was not visible. This cannot be explained by the supposition that the tail rendered the head invisible, inasmuch as the fog did not prevent the stars being seen as usual at night in all places where it prevailed.

It has been suggested that the position of the head might have been such, that it rose and set with the sun, or nearly so, and could not therefore be seen in the absence of that luminary either before sunrise or after sunset. But although this might be admitted for a very short interval, its continuance for a month would not be compatible with what is known of the motion of comets. If it were a comet, the tail being generally turned from the sun, the head must have been within the earth's orbit, and between the earth and sun, or nearly so. The angular motion of the comet must have been such as to remove it from the position of inferior conjunction in the course of a few days, after and before which the head would have either risen before the sun, or set after it, and so would have been visible. No such object, however, was seen at or near the time of the great fog of 1783.

No combination of any possible orbital motion of the comet with the orbital and diurnal motion of the earth has been or can be suggested which would be compatible with the position and continuance of the great dry fog of 1783. It may therefore be concluded that that phenomenon did not arise from the immersion of the earth in the tail of an unseen comet.

The great fog of 1831 is subject to nearly the same observations, and the cometary hypothesis is removed by nearly the same reasoning. This fog was manifested during the month of August. It spread over the three continents of the northern hemisphere, commencing on the north coast of Africa on the 3rd, at Odessa on the 9th, throughout France on the 10th, in the United States on the 15th, and in China during the latter part of the month.

The sun's light was so enfeebled, that it could be looked at without coloured or smoked glass. On the coast of Africa, the sun was not visible at all at altitudes below 15° or 20°; yet the nights were so clear, that the stars were visible. Observers in the north of Africa, in the south of France, in the United States, and in China, reported that the disk of the sun seen through the fog had the tint of azure, and in some places of emerald green.

This appearance was explained by the supposition of the well-known optical illusion called "accidental colours." The fog or the clouds around the solar disk, and through which the latter was seen, being, like fogs and clouds in general, when seen by the transmitted light of the sun, reddish, the white disk of the sun seen in juxta-position with them would, by the mere effect of contrast, appear to be bluish or greenish, according to the tint of red transmitted by the surrounding clouds.*

Like the great fog of 1783, this fog seemed to have a proper light. During its prevalence there was, strictly speaking, no nocturnal darkness. During the month of its prevalence there was light enough at midnight to read the smallest written or printed characters. This fact was reported equally by observers in places the most distant, as in Italy, Prussia, Siberia, &c.

Since twilight ceases when the depression of the sun below the horizon exceeds 18°, and since at these places, in August, the depression considerably exceeds that limit, it is evident that the light thus observed could not have been common twilight.

Whatever may be the explanation of this phenomenon, that of the immersion of the earth in the tail of a comet is overthrown completely by the fact that the fog, though extensively spread, was not continuous, much less uniform. Some parts of the European continent were altogether or nearly free from it, and in other parts it was developed in very different degrees. The times of its continuance in different places also varied much and irregularly, and in such a manner as to be quite incompatible with the cometary hypothesis.

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* See Lardner's "Hand-Book of Natural Philosophy" (1159).

The cometary hypothesis, then, being rejected, it has been suggested that these fogs may have had much nearer and less extraordinary causes. It was recorded that great physical commotions were manifested at opposite extremities of Europe in the year 1783. In the month of February terrible and long-continued shocks of an earthquake took place in Calabria, which produced great devastation, and by which more than 40,000 inhabitants of that country were buried under the ruins of overturned houses and buildings, and in the profound crevices of the cracked crust of the earth. At a later part of the year, Mount Hecla underwent the most violent eruptions ever witnessed, and new craters were opened at various points at the bottom of the surrounding sea, and even at considerable distances from the shore.

Considering these and like commotions, it has been suggested that the vapour, smoke, and gaseous matter ejected in enormous quantities during such eruptions, dissipated by the winds, might have been diffused through the atmosphere over the countries where the fog prevailed.

Another supposition assigns these fogs to the same cause as that which produces showers of meteoric stones, noticed in another number of this series. Among the various forms assumed by this class of bodies, that of showers of fine dust is not unusual. Now, we have only to admit the possibility of a still greater degree of attenuation, to reduce such dust to the condition of the matter composing a dry fog. This explanation would be quite compatible with the local and unequal distribution of the phenomenon.

Several medical authorities conjectured that the fog of 1831 might have been the cause of the epidemic cholera which prevailed about that time. This supposition, however, is overturned by the fact of the frequent prevalence of the same epidemic since then, at epochs at which no such fogs were seen.

12. Nevertheless, facts are recorded which render it certain the atmospheric disturbances and currents do produce extraordinary and hitherto unexplained effects upon epidemic diseases. A very curious and remarkable instance of this influence is quoted by M. Arago from the narrative of Matthew Dobson, an English traveller.

"A periodical wind, called Harmattan, blows three or four times a-year from the interior of the African continent towards the Atlantic coast, between latitudes 15° north, and 1° south. The periods of its prevalence are stated to be chiefly from the end of November to the beginning of April, its direction varying from east-south-east to north-north-east. Its duration at any one time varies from one to six days, and its force is always very moderate. A fog, thick enough to render the disk of the sun red, always accompanies this wind. The particles deposited by this fog upon the leaves of vegetables and on the black skin of the natives appears always white, but the nature of this whitish matter was not ascertained. It was remarked that this fog was speedily dissipated by the sea; for although the wind was sensible on sea at many leagues from the coast, the fog became rapidly less dense, and, at the distance of little more than a league, it disappeared.

"One of the characteristics of this wind and fog is extreme dryness. When it continued for any time, the foliage of the orange and lemon trees exposed to it became shrivelled and withered. So extreme is this dryness, that the covers of books, even when closed, locked in chests, and enveloped in linen cloth, were curved by it just as if they had been exposed to the heat of a strong fire. The panels of doors and frames of windows, and the furniture, were often cracked and broken by it. Its effects upon the human body were not less marked. The eyes, lips, and palate were parched and painful. If the wind continued unabated so long as four or five days, the face and hands grew pallid. The natives endeavoured to counteract these effects by smearing their skin with grease."

Considering all these effects, it might be naturally inferred that the Harmattan must be highly insalubrious; yet observation proved it to have the extreme opposite quality. It was found that its first breath completely banished intermittent fevers. Those who had been enfeebled by the practice of excessive bleeding, then prevalent there, soon recovered their strength. Epidemic and remittent fevers, which had a local prevalence, disappeared as if by enchantment. But the most wonderful effect of this atmospheric phenomenon was, that it rendered infection incommunicable, even when applied by artificial means, such as inoculation.

There was at Wydah, in 1770, a British slave ship called the *Unity*, having on board a cargo of above 300 negroes. The small-pox having broken out among them, the owner resolved on inoculating those who had not taken the natural disease. All those who were inoculated before the commencement of the Harmattan took the disease, but of seventy that were inoculated on the second day after its commencement, not one took the infection; yet after the lapse of some weeks, when the Harmattan ceased these seventy negroes took the natural disease. Soon after they were attacked by it, the Harmattan recommenced, and the disease almost immediately disappeared.

The country over which the Harmattan blows, for more than a hundred leagues, is a series of extensive plains covered with verdure, with a few patches of wood here and there, and intersected by a few rivers, with some small lakes.

13. Various phenomena have raised the question whether at any remote epoch of its physical history the earth was ever struck by the solid nucleus of a comet.

We have already stated the circumstances which render it highly probable that the comets generally are mere masses of aëriform or vaporous matter. Nevertheless, although this be certain as respects the large majority of these bodies, some among them, more especially those which appeared at remote dates, have had a splendour which it would be difficult to imagine to be produced by the reflection of the sun's light by mere vaporous matter; and even in modern times, since the instruments of observation have been improved, and observers have increased in zeal, activity, and vigilance, and have been greatly multiplied in number, appearances of a nucleus have been observed which some astronomers have considered to afford pretty conclusive evidence of the existence of a solid nucleus within the nebulous envelope; and although many entertain doubts of this, it cannot be said that the existence of a solid nucleus in some of the many comets which have passed through the system is absolutely disproved.

Assuming, then, the possible existence of a solid comet, and considering the possible (however improbable) eventuality of such a body and the earth passing at the same moment through the same point of space, it may be reasonably asked,

What would be the consequences of such a catastrophe?

It must be observed, in the first place, that admitting the bare possibility of certain comets having a solid nucleus, such a mass must be less, incomparably, than the smallest body of the solar system. The grounds upon which this inference rests, have been already stated.

Now, assuming the earth to move round the sun, and at the same time to have a diurnal rotation upon a certain diameter as its axis, let us see what would happen if it were to receive suddenly a blow, from a much smaller solid mass encountering it.

If, in case of such an event, the earth had no previous motion of rotation, and if, as would probably happen, the direction of the blow given to it did not pass through its centre, it would receive a motion of rotation round an axis at right angles to the plane drawn through the direction of the blow and the centre of the earth, and the time of rotation would depend on the distance of the centre of the earth from the direction of the blow.

If, however, the earth, before receiving the blow, had already a motion of rotation, the effect of the blow would be to change either its axis of rotation or the time of rotation, or both one and the other. Its new axis of rotation would have a certain position between its previous axis and that upon which the blow would have made it revolve if it had no previous rotation. The determination of this new axis would be a problem of no difficulty.

Such being the immediate consequences of such a collision, it remains to consider what would be its secondary results.

If a carriage moving uniformly on the smooth surface of a railway, or a boat propelled or drawn uniformly on the surface of water, receive an impulse by which its speed is suddenly changed, all loose bodies upon it will be thrown backward or forward, according as its speed is increased or diminished, inasmuch as they do not at first participate in the increase or diminution of velocity imparted to the vehicle on which they are placed. Hence it happens, that if a horse going at speed suddenly retards his motion, or stops, the rider is thrown forward, and if he suddenly starts forward with increased speed, the rider is thrown backwards.

A similar disturbance of position would be produced by a change of direction of the motion of the vehicle. If it suddenly turn to the right, loose bodies will fall to the left, and *vice versâ.*

The earth, moving in its annual course round the sun, and at the same time revolving uniformly upon its axis, producing the vicissitudes of day and night and the succession of seasons, must be regarded as a vehicle upon which all loose bodies, such as air, water, and other fluids, animals, and all natural and artificial objects, not planted and firmly fixed in the solid ground, are transported, first round the axis of rotation by the diurnal motion, and secondly, round the sun by the annual motion of the earth in its orbit. Now if, under such circumstances, either of these motions were to receive a sudden change either in velocity or direction, the fluids composing the atmosphere, and the oceans, seas, lakes, and rivers, not partaking of that change, would, for the reasons explained above, be thrown from their position of relative equilibrium. Violent atmospheric commotions would ensue. The waters of the oceans and seas, thrown from their beds, would inundate the continents; rivers would change their directions, and either run in new channels or inundate the surrounding plains; lakes would desert their positions, and would flow in any channels open to them, or would flood the surrounding countries. Animals would be precipitated against all solid objects near them, with a force greater probably than that of a cannon-ball. Trees would be torn from their roots; buildings, especially such as have much elevation, would be overthrown; and if the change of motion were of a certain intensity, lofty mountain peaks would be cast into the adjacent plains or valleys. It is evident that a general destruction of the organised world would be inevitable.

But even though the change of axis and the change of velocity of rotation of the earth might be so very inconsiderable, owing to the smallness of the mass of the striking comet and other causes, that such devastation might not take place, other effects would ensue which would speedily show the disturbance consequent on such a catastrophe. The least change in the axis would cause a corresponding change in the position of the terrestrial poles and the equator. The latitudes and longitudes of all places on the earth would suffer a change, the extent of which would be commensurate to the change of position of the axis of rotation.

But it is demonstrated in mechanics that a spheroid, such as the earth is known to be, cannot permanently revolve round any axis except its shortest diameter, that is the diameter which passes through the two points which form the centres of its flatness; and such we know by exact and numerous observations to be the axis upon which the earth actually revolves. Now, if by the collision of a solid comet the earth were made to revolve on any other diameter, it could not continue so to revolve. It would change its axis from hour to hour until at length it would again revolve round its shortest diameter.

But during this continual change of axis, what inconceivable physical and geographical confusion would arise! Not only would the latitudes and longitudes of places be constantly changed, but their climates and seasons, the conditions and qualities of their vegetable productions would undergo corresponding variations. Animals would migrate from country to country, seeking a congenial climate, and flying from vicissitudes and extremes of temperature which their instincts would not fail to tell them are incompatible with their well-being. The distribution of land and water, though perhaps exempt from the devastating effects attending extreme changes of velocity and direction, would nevertheless gradually undergo a total and general change, and the geographical features of the earth, the land-marks of nations and races, would be utterly deranged and effaced.

To answer the question, then, whether the earth has ever at any epoch been struck by the solid nucleus of a comet, we have only to examine whether there be any traditions in history, or any physical traces on the surface of the globe, of phenomena such as we have described above.

It is scarcely necessary to observe that, in the records of history and the traditions of nations, there are no traces of any such catastrophe as that which we have here described. The deluge, which we shall presently notice, did not correspond to the conditions stated. That there are indications on the crust of the earth which prove that many parts of the continents, now elevated to considerable heights above the level of the sea, were at some former epoch submerged, is incontestable. The researches of geologists have established this fact. But the manner in which these marine deposits are found to be disposed is not such as a change in the earth's axis or in its time of rotation would explain. These deposits are frequently horizontal, of great breadth, very thick, and very regular. The varied and often very small shells found in them have preserved their most delicate points, their most brittle parts, unbroken. Every circumstance, then, dissipates the idea of a violent transposition; everything shows the deposits to have been formed on the spot. What now remains to complete the explanation without having recourse to an eruption of the sea? It must be admitted that the mountains and undulating grounds upon which they are based have risen up from below, like mushrooms; that they have grown up through the bosom of the waters. In 1694, Halley already cited this hypothesis as a *possible* explanation of the presence of marine productions upon the sides and on the summits of the highest mountains. This explanation is at present generally admitted. A comet which should perceptibly alter either the movement of rotation or the progress of translation of the earth would, without any doubt, occasion terrific convulsions in the shell of the globe; but, it must be repeated, these physical revolutions would differ in a thousand circumstances from those which are at present the objects of geological research.

14. *Has the geographical condition of the earth been ever disturbed by the near approach of a comet? Can the biblical deluge have been produced by such a cause?*

A remarkable comet appeared in the year 1680, which has been rendered memorable by the attempt of Whiston to prove that it was periodic, and that on one of its former visits it was the proximate cause of the Mosaic deluge. Arago, in his essays on comets, has discussed fully the question raised by Whiston.

Whiston proposed to show not only in what manner a comet might have occasioned the deluge of Noah, but was desirous, moreover, that his explanation should agree minutely with all the circumstances of that great catastrophe as related in Genesis. Let us see how he has succeeded in his object.

The biblical deluge happened in the year 2349 before the Christian era according to the modern Hebrew text; or the year 2926, after the Samaritan text, the Septuagint, and Josephus. Is there, then, reason to suppose that at either of those periods a great comet had appeared?

Among the comets observed by modern astronomers, that of 1680 may, from its brilliancy, without hesitation, be placed in the first rank.

A great many historians, both native and foreign, mention *a very large comet, in similitude to the blaze of the sun, having an immense train,* which appeared in the year 1106. In ascending still higher, we find a very large and terrific comet designated by the Byzantine writers by the name of Lampadias, because it resembled a burning lamp, the appearance of which may be fixed in the year 531. A comet appeared in the month of September, in the year of the death of Cæsar, during the games given by the Emperor Augustus to the Roman people. That comet was very brilliant, as it became visible from the eleventh hour of the day, that is, about five o'clock in the evening, or *before sunset.* Its date is in the year 43 before our era.

Let us, then, compare the dates of these appearances:—

From 1106 to 1680 we find	574 years.
,, 531 ,, 1106 ,, ...	575 ,,
,, 43 B.C. to 531 we find . . .	575 ,,

These periods may be regarded as equal to each other, and thence it appeared probable enough that the comets of the death of Cæsar, of 531, of 1106, and of 1680, have been only the reappearances of one and the same comet, which, after having run through its orbit—after having made its complete revolution in about five hundred and seventy-five years—became again visible from the earth. Then if the period of five hundred and seventy-five years is multiplied by four, we have twenty-three hundred, which, added to 43, the date of Cæsar's comet, gives, with the difference of only six years, the epoch of the deluge, resulting from the modern Hebrew text. In multiplying by five, the date of the Septuagint is found within eight years.

If we recollect the marked differences of the comet of 1759 in the period of its revolution round the sun, we shall acknowledge that Whiston might legitimately have felt authorised to suppose that the great comet of 1680, or of the death of Cæsar, was near the earth at the period of Noah's deluge, and that it had some part in that great phenomenon.

We shall not stop to explain minutely the series of transformations by which the earth, which, according to Whiston, was originally a comet, became the globe we now inhabit. It is enough to observe that he considered the nucleus of the earth as a hard and compact substance, which was the ancient nucleus of the comet; that the matters of various natures confusedly mixed which composed the nebulosity, subsided more or less quickly, according to their specific gravities; that then the solid nucleus was at first surrounded by a dense and thick fluid; that the earthy matters precipitated themselves afterwards, and formed a covering over the dense fluid—a kind of crust, which may be compared to the shell of an egg; that the water, in its turn, came to cover this solid crust; that in a considerable degree it became filtered through the fissures, and spread itself over the thick fluid; that, in fine, the gaseous matters remaining suspended, purified themselves gradually, and constituted our atmosphere.

Thus, according to his theory, the great biblical abyss is supposed to consist of a solid nucleus and of two concentric orbs. Of these orbs, that nearest to the centre is formed of a heavy fluid which first precipitated itself; the second is of water; it is then, properly speaking, upon the last of these fluids that the exterior and solid crust of the earth reposes.

It is proper now to examine how, after the constitution of the globe to which at least many geologists could oppose more than one difficulty, Whiston explains the two principal events of the deluge described by Moses.

"In the six hundredth year of Noah's life," says the book of Genesis, "on the seventeenth day of the second month, the same day were *all the fountains of the great deep broken up, and the windows of heaven were opened.*"

At the period of the deluge, the comet of 1680, says Whiston, was only nine or ten thousand miles from the earth: it attracted, therefore, the water from the great deep, as the moon at present attracts the waters of the ocean. Its action, on account of that great proximity, must have tended to produce an immense tide. The terrestrial shell could not resist the impetuosity of the inundation; it broke in at a great number of points, and the waters, then free, spread themselves over the continents. The reader will here recognise *the rupture of the fountains of the great deep.*

The ordinary rains of our days, even continued for forty days, would have produced but a small accumulation. In taking for daily rain that which falls at Paris annually, the produce of six weeks, far from covering the highest mountains, would scarcely have formed a depth of eighty feet. It was therefore necessary to refer to other sources *than the cataracts of heaven.* Whiston has found them in the nebulosity and tail of the comet.

According to him, the nebulosity reached the earth near the Gordian (Ararat) mountains. Those mountains intercepted the entire tail. The terrestrial atmosphere, thus charged with an immense quantity of aqueous particles, was sufficient to produce forty days' rain of such violence as the ordinary state of the globe can give us no idea.

Notwithstanding all its strangeness, we have stated the theory of Whiston in detail, both on account of the celebrity which it has so long enjoyed, as well as because of the consideration due to the man whom Newton himself designed as his successor in the University of Cambridge; yet the following are objections which it seems his theory cannot resist.

Whiston having required an immense tide to explain the mystery of the biblical phenomena of the great deep, was not content to pass his comet extremely near the earth at the moment of the deluge: he has, moreover, given it a very great magnitude, in supposing it six times greater than the moon.

Such a supposition is completely gratuitous, but this is its least fault; for it is not sufficient to account for the phenomena. If the moon produces a tide on the waters of the ocean, it is because its angular diurnal motion is not very considerable; that in the space of some hours its distance from the earth scarcely varies; during a considerable time it remains vertically over almost the same points of the globe; the fluid which it attracts has therefore always time to yield to its action before it moves to a region where the force which emanates from it will be otherwise directed. But it was not the same with the comet of 1680. Near to the earth, its apparent angular motion must have been extremely rapid; in a few minutes it corresponded with a numerous series of points situated on terrestrial meridians very distant from each other. As to its rectilinear distance from the earth, it might, without doubt, have been very small, but only during a few instants. The union of these circumstances, it must be observed, was but little favourable to the production of a great tide.

It is true that, to diminish these difficulties, it is sufficient to increase the comet—to make its mass not only six times the size of the moon, but thirty or forty times larger: but the comet of 1680 does not afford that latitude. On the 1st of November in that year it passed very near to the earth. It is shown that at the period of the deluge its distance was not less; then, as in 1680 it produced neither celestial cataracts, nor terrestrial tides, nor ruptures of the great deep; as, moreover, its train nor its nebulosity did not inundate us, we may in all confidence say that Whiston's theory is a mere romance, unless, in abandoning the comet of 1680, we venture to attribute the same effect to another much more considerable object of the same description.

In fine, we must observe that, even the argument of Whiston, based upon the apparent equality of the supposed successive appearances, from which he deduces a period of 574 or 575 years for the comet in 1680, is shaken by more recent calculations, which give to that body* an elliptic orbit in which the period is 8813 years.

15. The probability of the terrestrial equilibrium being injuriously deranged by the near approach of a comet, which, nevertheless, does not actually come in contact with the earth, is reduced to nothing by the established fact that the masses of these bodies generally are so utterly insignificant that none of them has ever yet produced by its proximity the slightest sensible deviation from its customary path in the smallest body of the solar system.

16. Notwithstanding the many arguments which we have here developed against the probability of any fatal influence exerted by comets upon our planet, it must not be concealed that high authorities have regarded such influences and effects as not impossible. Thus Laplace, referring to the possible collision of a solid comet with the earth, says: "It is easy to foresee the effects of such an eventuality: the earth's axis and rotation changed: the waters of the seas and oceans deserting their beds, and rushing towards the new equator: the chief part of the human race and inferior animals drowned in an universal deluge, or destroyed by the violence of the collision: whole species annihilated:—all monuments of human industry overturned!" Notwithstanding the many and obvious evidences against the geological phenomena having been produced by such a cause, Laplace did not reject it, probably because the phenomena were not so fully known at the time he wrote as they are at present. "We see then," he observed, "why the ocean deserted the most lofty mountains, on which it left, however, incontestable evidence of its presence. We see why the animals and plants of the tropics may have existed in the higher latitudes, where their relics and footsteps are still seen. In fine, it explains the recent date of the present races, whose earliest monuments do not go further back than about 3000 years. The human race, reduced to a small group of individuals, in a deplorable condition, occupied exclusively in providing for their physical wants, must necessarily have lost the remembrances and records of all the sciences and arts; and when later, new wants were created by the progress of civilisation, all was to be recommenced as if no previous progress had been made, and as if man had been then for the first time placed upon the earth."

17. Having disposed of the question of the physical influences imputed to comets, we shall conclude this notice by a brief statement of one of the most extraordinary and unexplained phenomena

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* Lardner's "Handbook of Natural Philosophy and Astronomy." (3072).

ever witnessed in the heavens, which has been not only seen, but observed with the most scrupulous accuracy in our own times.

A periodical comet, called Biela's from its discoverer, revolves round the sun in an oval orbit of 6¾ years. On the occasion of its appearance in 1846, it was seen to resolve itself into two distinct comets, which, from the latter end of December, 1845, to the epoch of its disappearance in April, 1846, moved in distinct and independent orbits. The paths of these two bodies were in such optical juxtaposition, that both were always seen together in the field of view of the telescope, and the greatest visual angle between their centres did not amount to more than a third of the apparent breadth of the moon.

M. Plantamour, director of the Observatory of Geneva, calculated the orbits of these two comets, considered as independent bodies; and found that the real distance between their centres was, subject to but little variation while visible, about thirty-nine semi-diameters of the earth, or two-thirds of the moon's distance. The comets moved on thus side by side, without manifesting any reciprocal disturbing action; a circumstance no way surprising, considering the infinitely minute masses of such bodies.

The original comet was apparently a globular mass of nebulous matter, semi-transparent at its very centre, no appearance of a tail being discoverable. After the separation, both comets had short tails, parallel in their direction, and at right angles to the line joining their centres; both had nuclei. From the day of their separation the original comet decreased, and the companion increased in brightness until (on the 10th February) they were sensibly equal. After this the companion still increased in brightness, and from the 14th to the 16th was not only greatly superior in brightness to the original, but had a sharp and starlike nucleus compared to a diamond spark. The change of brightness was now reversed, the original comet recovering its superiority, and acquiring on the 18th the same appearance as the companion had from the 14th to the 16th. After this the companion gradually faded away, and disappeared previously to the final disappearance of the original comet on 22nd April.

It was observed also that a thin luminous line or arc was thrown across the space which separated the centres of the two nuclei, especially when one or the other had attained its greatest brightness, the arc appearing to emanate from that which for the moment was the brighter.

After the disappearance of the companion, the original comet threw out three faint tails, forming angles of 120° with each other, one of which was directed to the place which had been occupied by the companion.

It is suspected that the faint comet which was observed at Rome by Prof. Secchi to precede Biela's comet in 1852, may have been the companion thus separated from it; and if so, the separation must be permanent, the distance between the parts being greater than that which separates the earth from the sun.

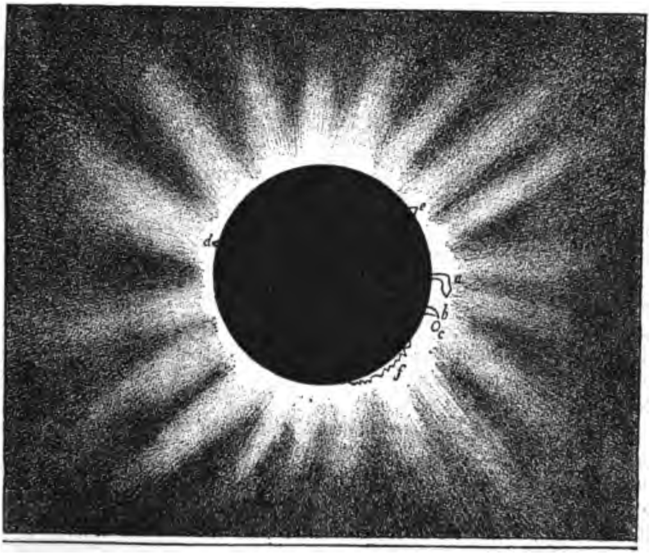

Fig. 13.

ECLIPSES.

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CHAPTER I.

1. Mutual interposition of celestial objects.—2. Their mutual obscuration.—3. Eclipses, transits, and occultations.—4. Solar eclipse.—5. Lunar eclipse.—6. Transit of a planet.—7. Occultation of a fixed star.—8. Appearance produced by transit of an inferior planet. SOLAR ECLIPSES: 9. Effects of the relative magnitude of the discs of the sun and moon.—10. Conditions which determine eclipses.—11. Conditions under which an eclipse does not take place.—12. Condition of external contact.—13. Condition of partial eclipse—determination of its magnitude.—14. Internal contact.—15. Annular eclipse.—16. Total eclipse.—17. Greatest possible duration of a total eclipse.—18. Condition of annular eclipses.—19. Greatest possible duration of annular eclipses.—20. Solar eclipses can only occur at or near a new moon.—21. Effects of parallax.—22. Data which determine the circumstances of eclipses.—23. Solar ecliptic limits.—24. Anecdote of Columbus.—25. Baily's beads.—26. These appearances produced by lunar mountains.—27. Flame-like protuberances round the dark disc of the moon.—

ECLIPSES.

28. Solar eclipse of 1851.—29. Observations of the Astronomer Royal upon it.—30. Observations of Messrs. Dunkin and Humphreys upon it.—31. Observations of Mr. W. Gray upon it.—32. Observations of Messrs. Stephenson and Andrews at Fredrichsvaarn.—33. Observations of Mr. Lassell at Trollhättan Falls.—34. Observations of Mr. Hind at Ravelsborg, near Engelholm.

1. Of the objects which in such countless numbers are scattered over the firmament, all those which constitute the solar system, except the sun itself, are in motion; and it must necessarily happen, occasionally, that some of them will assume a position between others and the eye of the observer placed upon the earth. When such an event happens the nearer of the two will intercept wholly or partially the view of the more distant. If the apparent magnitude of the nearer be greater than the more distant, such an obstruction may be total, but if less it can only be partial.

2. Since all the bodies of the solar system are illuminated by the sun, and when deprived of the sun's light are obscured and cease to be visible, it may also happen that some one of the bodies composing the system may intervene between the sun and another body, so as to deprive the latter of the light which it receives from that luminary. In such a case the object deprived of light will be rendered wholly or partially invisible, according to the relative magnitude of the two bodies, the one intercepting the light and the other being obscured.

3. Such conjunctions produce a class of occasional astronomical phenomena, which are invested with a high popular as well as a profound scientific interest. The rareness with which some of them are presented, their sudden and, to the vulgar mass, unexpected appearance, and the singular phenomena which often attend them, strike the popular mind with awe and terror. To the astronomer, geographer, and navigator, they subserve important uses, among which the determination of terrestrial longitudes, the more exact estimation of the sun's distance from the earth (which is the standard and modulus of all distances in the celestial spaces), and, in fine, the discovery of the mobility of light, and the measure of its velocity, hold foremost places.

The phenomena resulting from such contingencies of position and direction are variously denominated ECLIPSES, TRANSITS, and OCCULTATIONS, according to the relative apparent magnitudes of the interposing and obscured bodies, and according to the circumstances which attend them.

4. When the disc of the moon passes between an observer and the disc of the sun, it intercepts in this manner more or less

of the latter, and produces the phenomenon called a *solar eclipse.*

5. When the globe of the earth intervenes between the moon and the sun, it intercepts the light of the latter from a greater or lesser part of the moon's disc, and produces the phenomenon called a *lunar eclipse.*

6. When a satellite of a planet passes into such a position that the globe of the planet intervenes between the satellite and the sun, the latter is eclipsed.

7. When the disc of the moon or of a planet passes between the eye of an observer and a fixed star, the star suddenly disappears, and the phenomenon is called an *occultation* of the star.

8. When a planet passes between an observer and the sun's disc there is seen projected upon the latter a small black circular spot, and in virtue of the relative motion of the sun and planet this black spot appears to pass across the disc of the sun from east to west, producing the phenomenon called a transit of the planet. Since at the period of a transit the planet must be between the sun and the earth, and therefore nearer to the sun than the earth, this phenomenon can only happen with an inferior planet. The only planets, therefore, of which there can be transits are Venus and Mercury.

SOLAR ECLIPSES.

9. The discs of the sun and moon, though nearly equal, are not exactly so, each being subject to a variation of magnitude confined within certain narrow limits; and, in consequence, the disc of the moon is sometimes a little greater, and sometimes a little less, than that of the sun. Their centres move in two apparent circles on the firmament; that of the sun in the ecliptic, and that of the moon in a circle inclined to the ecliptic at a small angle of about 5°. These circles intersect at two opposite points of the firmament, called the moon's nodes. In consequence of the very small obliquity of the moon's orbit to the ecliptic, the distance between these paths, even at a considerable distance at either side of the node, is necessarily small. Now, since the centres of the discs of the sun and moon must each of them pass once in each revolution through each node, it will necessarily happen from time to time that they will be both at the same moment either at the node itself, or at some points of their respective paths so near it, that their apparent distance asunder will be less than the sum of their apparent semi-

diameters, and either total or partial interposition must take place, according to the relative magnitudes of their discs, and to the distance between the points of their respective paths at which their centres are simultaneously found.

10. This will be easily rendered intelligible. Let A, fig. 1, be the disc of the object eclipsed, and *a* be that of the interposing object which eclipses it. So long as the distance between the centres of the two discs is greater than the sum of their semi-diameters, it is evident that the one disc will lie altogether outside the other, so as not to intercept the view of any part of it. This will be apparent from an inspection of fig. 1.

11. This may be briefly explained thus: If R be the semi-diameter of A, and r that of *a*, and D be the distance between the two centres, then the one disc will lie altogether outside the other so long as D is greater than $R + r$.

Fig 1.

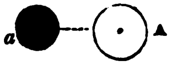
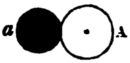


Fig. 2.



12. If the distance between the centres be equal to the sum of the two semi-diameters, then the two discs will touch each other, without either actually intercepting a part of the other. This case is shown in fig. 2, and is briefly explained thus: If $D = R + r$, the two discs will touch without encroaching one upon the other. This position of the discs is called *external contact.*

13. If the distance between the centres of the two discs be less than the sum of the two semi-diameters, then one of the discs will necessarily encroach upon the other and a partial eclipse will take place. This case is shown in fig. 3. The breadth of the part of the disc A obscured by *a* is evidently equal to the difference between the sum of the semi-diameters of the two discs and the distance between their centres, which is briefly expressed thus: If $R + r$ be greater than D, then the one disc will encroach upon the other, and the breadth of the part intercepted will be

$$R + r - D.$$

Fig. 3.

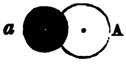
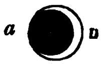


Fig. 4.



14. If the distance between the centres of the two discs be

equal to the difference of the semi-diameters, then the one disc will lie within the other, just touching it, as shown in fig. 4. This position of the disc is called that of *internal contact*, which therefore takes place when

$$D = R - r.$$

15. If the distance between the centres be less than the sum of the semi-diameters, but greater than their difference, then a partial interposition will take place, as shown in fig. 3. If the interposing disc be less than the obscured disc, and the distance between their centres be less than the difference between the semi-diameters, then the interposing disc will lie within the obscured disc, leaving a round ring of illuminated surface, not intercepted, as shown in fig. 5. If, in this case, the centres of the two discs coincide, the surrounding ring of light will be of uniform breadth.

Fig. 5.

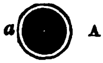


Fig. 6.

Such phenomena are called *annular eclipses*, and when the centres coincide they are said to be centrical and annular.

16. If the interposing disc be greater than the intercepted one, and at the same time the distance between the centres less than the difference of the semi-diameters, then the interposing disc will cover completely the other, and a total eclipse will take place, as shown in fig. 6. If in this case the centres of the two discs coincide, the eclipse is said to be total and central. In the case of the sun and moon the magnitude of eclipses are expressed by what are called *digits*. If the diameter of the eclipsed object, be it sun or moon, be supposed to be divided into twelve parts, each of which is called a *digit*, the eclipse is said to measure as many digits as there are such parts in the greatest breadth of the obscured part, that is, in the difference between the sum of the semi-diameter of the sun and moon and the distance between their centres. To produce a total solar eclipse, it is therefore necessary, 1st, that the apparent diameter of the moon should be equal to or greater than that of the sun; and, 2ndly, that the apparent places of their centres should approach each other within a distance not greater than the difference of their apparent semi-diameters. When these conditions are fulfilled, and so long as they continue to be fulfilled, the eclipse will be total.

17. The greatest value of the apparent semi-diameter of the moon being 1006″, and the least value of that of the sun being 945″, we shall have for the difference of their semi-diameters 61″. The greatest possible duration, therefore, of a total solar eclipse will be the time necessary for the centre of the moon to gain upon that of the sun 61″ × 2 = 122″. But since the mean synodic motion of the moon is at the rate of 30″ per minute, it follows that the duration of a total solar eclipse can never exceed four minutes.

18. When the apparent diameter of the moon is less than that of the sun, its disc will not cover that of the sun, even when concentrical with it. In this case, a ring of light would be apparent round the dark disc of the moon, the breadth of which would be equal to the difference of the apparent semi-diameters, as represented in fig. 5. When the discs are not absolutely concentrical, the distance between their centres being, however, less than the difference of their apparent semi-diameters, the dark disc of the moon will still be within that of the sun, and will appear surrounded by a luminous annulus, but in this case the ring will vary in breadth, the thinnest part being at the point nearest to the moon's centre; and when the distance between the centres is reduced to exact equality with the difference of the apparent semi-diameters, the ring becomes a very thin crescent, the points of the horns of which unite, as represented in fig. 4.

The greatest breadth of the crescent will be in this case equal to the difference of the apparent diameters of the sun and moon.

The greatest apparent semi-diameter of the sun being 16′ 18″, and the least apparent semi-diameter of the moon being 14′ 44″, the greatest possible breadth of the annulus when the eclipse is centrical will be

$$16' \, 18'' - 14' \, 44'' = 1' \, 34'' = 94'',$$

which is about the 20th part of the mean apparent diameter of the sun.

19. The greatest interval during which the eclipse can continue annular is the time necessary for the centre of the moon to move synodically over 94″ × 2 = 188″, and, since the mean synodic motion is at the rate of 30″ per minute, this interval will be about

$$\frac{188}{30} = 6{\cdot}26 \text{ minutes, or about six minutes and a quarter.}$$

20. Solar eclipses can only occur at or near a new moon. This

is evident, because the condition which limits the apparent distance between the centres of the discs to the sum of the apparent semi-diameters, involves the consequence that this distance cannot much exceed 30′, and as the difference of longitudes must be still less than this, it follows that the eclipse can only take place within less than half a degree in apparent distance, and within less than two hours of the epoch of conjunction.

21. Since the visual directions of the centres of the discs of the sun and moon vary more or less with the position of the observer upon the earth's surface, the conditions which determine the occurrence of an eclipse, and if it occur, those which determine its character and magnitude, are necessarily different in different parts of the earth. While in some places none of the conditions are fulfilled, and no eclipse occurs, in others an eclipse is witnessed which varies from one place to another in its magnitude, and in some may be total while it is partial in others.

If the change of position of the observer upon the earth's surface affected the visual directions of the centres of the two discs equally, which would be the case if they were equally distant, or nearly so, no change in the apparent distance between them would be produced, and in that case the eclipse would have the same appearance exactly to all observers in every part of the earth. But the sun being about 400 times more distant than the moon, the visual direction of the centre of its disc is affected by any difference of position of the observers, to an extent 400 times less than that of the moon's centre.

22. The relative positions of the discs of the sun and moon in the firmament, their apparent motions, and the effect produced upon their apparent positions by the varying positions of the observer upon the earth, being all known, the circumstances which determine the magnitude from minute to minute of the distance between their centres, are all given; and the problem to determine the beginning of the eclipse, or the moment at which the distance between the centres becomes equal to the sum of their apparent diameters; and the end of the eclipse, or the moment when, after diminishing and then increasing, it again becomes equal to the sum of their apparent diameters, is a matter of easy arithmetical calculation, although the practical details of such processes would not be suitable to the readers of this Tract.

23. The moon's orbit being inclined to the ecliptic at an angle of 5°, and, consequently, the distance of the moon's centre from the ecliptic varying in each month from 0° to 5°, while the interposition of the moon between any place on the earth and the sun, requires that the apparent distance of their centres should

not exceed the sum of their apparent semi-diameters, which never much exceeds half a degree, it is clear that an eclipse can never happen except when, at the time of conjunction, the apparent distance of the moon's centre from the ecliptic is within that limit, a condition which can only be fulfilled within certain small distances of the moon's nodes.

There is a certain distance from the moon's node, beyond which a solar eclipse is impossible, and a certain lesser distance, within which that phenomenon is inevitable. These distances are called the solar ecliptic limits.

24. Columbus is said to have availed himself of his acquaintance with practical astronomy to predict a solar eclipse, and used the prediction as a means of establishing his authority over the crews of his vessels, who showed indications of mutinous disobedience.

The spectacle presented during a total eclipse is always most imposing. The darkness is sometimes so intense as to render the brighter stars and planets visible. A sudden fall of temperature is sensible in the air. Vegetables and animals comport themselves as they are wont to do after sunset. Flowers close, and birds go to roost. Nevertheless, the darkness is different from the natural nocturnal darkness, and is attended with a certain indescribable unearthly light, which throws upon surrounding objects a faint hue, sometimes reddish, and sometimes cadaverously green.

Many interesting narratives have been published by scientific observers who have been so fortunate as to witness these phenomena.

25. When the disc of the moon, advancing over that of the sun, has reduced the latter to a thin crescent, it was observed by Mr. Francis Baily, that immediately before the beginning, or after the end of complete obscuration, the crescent appeared as a band of brilliant points separated by dark spaces, so as to give to it the appearance of a string of brilliant "beads." The phenomenon, which has since been frequently re-observed, thence acquired the name of "Baily's beads."

Further observation showed, that, before the formation of the "beads," the horns of the crescent were sometimes interrupted and broken by black streaks thrown across them.

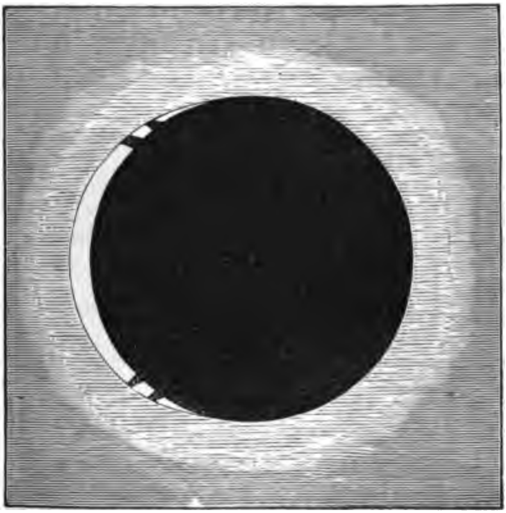
These phenomena are roughly sketched in figs. 7, 8.

Figs. 9, 10, 11, 12, are taken from the original sketches of Mr. Baily, representing the progressive disappearance of the beads after the termination of the complete obscuration.

26. These phenomena arise from the projections of the edge of the moon's disc, serrated by numerous inequalities of the surface,

approaching so close to the external edge of the sun's disc, that the points of the projections extend to the latter, while the

Fig. 7.



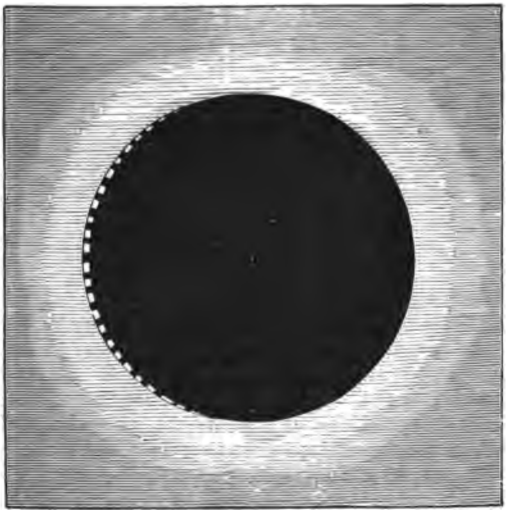


Fig. 8.

darkness nearly equal in both cases), or from whatever cause, the suddenness of the darkness in 1851 appeared to me much more striking than in 1842. My friends who were on the upper rock, to which the path was very good, had great difficulty in descending. A candle had been lighted in a lantern about a quarter of an hour before the totality; Mr. Haselgren was unable to read the minutes of the chronometer-face without having the lantern held close to the chronometer.

"The corona was far broader than that which I saw in 1842: roughly speaking, its breadth was little less than the moon's diameter; but its outline was very irregular. I did not remark any beams projecting from it which deserved notice as much more conspicuous than the others; but the whole was beamy, radiated in structure, and terminated (though very indefinitely) in a way which reminded me of the ornament frequently placed round a mariner's compass. Its colour was white, or resembling that of *Venus*. I saw no flickering or unsteadiness of light. It was not separated from the moon by any dark ring, nor had it any annular structure; it looked like a radiating luminous cloud behind the moon.

"The form of the prominences was most remarkable. That which I have marked *a* reminded me of a bomerang. Its colour for at least two-thirds of its breadth, from the convexity towards the concavity, was full lake-red, the remainder was nearly white. The most brilliant part of it was the swell farthest from the moon's limb; this was distinctly seen by my friends and myself with the naked eye. I did not measure its height; but judging generally by its proportion to the moon's diameter, it must have been 3′. This estimation perhaps belongs to a later period of the eclipse. The prominence *b* was a pale white semi-circle based on the moon's limb. That marked *c* was a red detached cloud, or balloon, of nearly circular form, separated from the moon's limb by a space (differing in no way from the rest of the corona) of nearly its own breadth. That marked *d* was a small triangular or conical red mountain, perhaps a little white in the interior. These were the appearances seen instantly after the formation of the totality.

"I employed myself in an attempt to delineate roughly the appearances on the western limb, and I took a hasty view of the country; and I then examined the moon a second time. I believe (but I did not carefully remark) that the prominences *a b c* had increased in height; but *d* had now disappeared, and a new one *e* had risen up. It was impossible to see this change without feeling the conviction that the prominences belonged to the sun and not to the moon.

"I again looked round, when I saw a scene of unexpected beauty. The southern part of the sky, as I have said, was covered with uniform white cloud; but in the northern part were detached clouds upon a ground of clear sky. This clear sky was now strongly illuminated, to the height of 30° or 35°, and through almost 90° of azimuth, with rosy-red light shining through the intervals between the clouds. I went to the telescope, with the hope that I might be able to make the polarisation-observation, (which, as my apparatus was ready to my grasp, might have been done in three or four seconds,) when I saw that the *sierra*, or rugged line of projections, shown at *f*, had arisen. This *sierra* was more brilliant than the other prominences, and its colour was nearly scarlet. The other prominences had perhaps increased in height, but no additional new ones had arisen. The appearance of this *sierra*, nearly in the place where I expected the appearance of the sun, warned me that I ought not now to attempt any other physical observation. In a short time the white sun burst forth, and the corona and every prominence vanished.

"I withdrew from the telescope and looked round. The country seemed, though rapidly, yet half unwillingly, to be recovering its usual cheerfulness. My eye, however, was caught by a duskiness in the south-east, and I immediately perceived that it was the eclipse-shadow in the air travelling away in the direction of the shadow's path. For at least six seconds this shadow remained in sight, far more conspicuous to the eye than I had anticipated."

30. Owing to the unfavourable state of the atmosphere, the observations of the other members of the Admiralty party were not so satisfactory as those of its chief. Nevertheless, both observers saw the red prominences, though imperfectly, as compared with the results of the observations of the Astronomer Royal. Baily's beads were seen by Mr. Dunkin, as well before as after the total obscuration. Their appearance was of intense brilliancy, compared by the observer to a diamond necklace. Their effect on the observer was "quite overpowering," being unprepared for a sight so magnificent.

At Christianstad, the planets Venus, Mercury, and Jupiter, and the stars Arcturus and Vega, were visible during the totality of the eclipse.

31. Mr. W. Gray, stationed at Tune, near Sarpsborg, saw the beads, both before and after the total obscuration. He saw four of the red projections, three of which are represented in fig. 14, the fourth resembling *c* and *d* in form, and diametrically opposite to *a* in position on the moon's limb.

During the totality, the light seemed like that of an evening in August at an hour and a half after sunset.

32. Messrs. Stephenson and Andrews, at Fredrichsvaarn, saw Baily's beads both before and after the total obscuration. The crescent, before disappearing, was seen as a fine thread of light, which broke up into fragments, and when it re-appeared, it gave the idea of globules of mercury rushing amongst each other along the edge of the moon. In a second or two after the disappearance of the crescent, a rose-coloured flame shot out from the limb of the moon, which in form resembled a sickle (see fig. 15). It increased rapidly, and then two other rose-coloured prominences, above and below it, started out, differing in shape, but evidently of the same character. Besides these, there were, as well between them as elsewhere, around the moon's edge other lurid points and other indistinct lines. The height of the principal prominence was estimated at about the twentieth of the moon's diameter, that is, about 1½′. The chief prominences looked like burning volcanoes, and the lurid points and lines reminded the observers of dull streams of cooling lava.

Fig. 14.

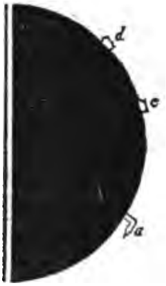
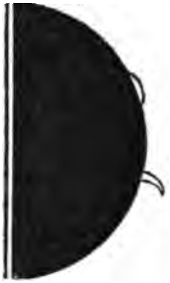
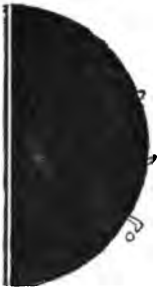


Fig. 15.



33. Mr. Lassell, at Trollhättan Falls, having heard the red prominences seen in former total eclipses described as faint appearances, saw with astonishment around the dark disc of the moon, after the commencement of total obscuration, prominences of the most brilliant lake colour,—a splendid pink, quite defined and hard, fig. 16. They appeared not to be absolutely quiescent. The observer judged from their appearance that they belonged to the sun, and not to the moon.

Fig. 16.



34. Mr. Hind, at Ravelsborg, near Engelholm, saw the beads, both before and after the total obscuration, in such a manner as to leave no doubt of their cause being that already explained. In five seconds after the commencement of the total obscuration, the corona or glory around the moon's disc was seen. Its colour seemed to be that of tarnished silver, brightest next the moon's limb, and gradually fading to a distance equal to one-third of her diameter, where it became confounded with the general tint of the heavens. Appearances of radiation are mentioned, similar to those described by Professor Airy.

"On first viewing the sun," says Mr. Hind, "without the dark glass after the commencement of totality, the rose-coloured prominences immediately caught my eye, and others were seen a few seconds later (fig. 17, p. 177). The largest and most remarkable of them was situate about 5° north of the parallel of declination, on the western limit of the moon; it was straight through two-thirds of its length, but curved like a sabre near the extremity, the concave edge being towards the horizon. The edges were of a full rose-pink, the central parts plainer, though still pink.

"Twenty seconds, or thereabouts, after the disappearance of the sun, I estimated its length at 45" of arc, and on attentively watching it towards the end of totality, I saw it materially lengthened (probably to 2′), the moon having apparently left more and more of it visible as she travelled across the sun. It was always curved, and I did not remark any change of form, nor the slightest motion during the time the sun was hidden. I saw this extraordinary prominence *four seconds after the end of totality*, but at this time it appeared detached from the sun's limb, the strong white light of the corona intervening between the limb and the base of the prominence.

"About 10° south of the above object I saw, during the totality, a detached triangular spot of the same rose colour, suspended, as it were, in the light of the corona, which gradually receded from the moon's dark limb, as she moved onwards, and was, therefore, clearly connected with the sun. Its form and position, with respect to the large prominence, continued exactly the same so long as I observed it. On the south limb of the moon appeared a long range of rose-coloured flames, which seemed to be affected with a tremulous motion, though not to any great extent.

"The bright rose-red of the tops of these projections gradually faded towards their bases, and along the moon's limb appeared a bright narrow line of a deep violet tint: not far from the western extremity of this long range of red flames was an isolated prominence, about 40" in altitude, and another of similar size and form, at an angle of 145° from the north towards the east: the moon was decidedly reddish purple at the beginning of totality, but the reddish tinge disappeared before its termination, and the disc assumed a dull purple colour. A bright glow, like that of twilight, indicated the position where the sun was about to emerge, and three or four seconds later the beads again formed, this time instantaneously, but less numerous, and even more irregular, than before. In five seconds more the sun reappeared as a very fine crescent on the sudden extinction of the beads."

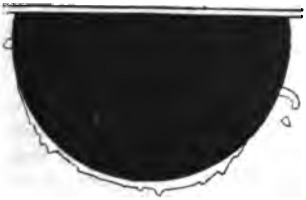


Fig. 17.

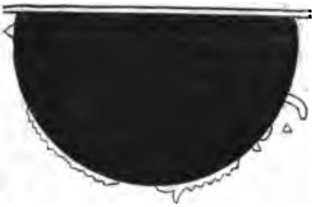


Fig. 18.

ECLIPSES.

CHAPTER II.

35. Observations of Mr. Dawes near Engelholm.—36. Effects of total obscuration on surrounding objects and scenery.—37. Evidence of a solar atmosphere.—38. Probable causes of the red emanations in solar eclipses. LUNAR ECLIPSES: 39. The earth's conical shadow.—40. Its section may be regarded as a dark disc moving on the firmament.—41. Conditions which determine lunar eclipses.—42. Lunar ecliptic limits.—43. Greatest duration of total lunar eclipses.—44. Effects of the earth's penumbra.—45. Effects of refraction of the earth's atmosphere in total lunar eclipse.—46. Lunar disc visible during total obscuration.

35. MR. DAWES near Engelholm observed the beads, and found all the circumstances attending their appearance, such as to leave no doubt as to the truth of the cause generally assigned to them. He observed the corona, a few seconds after the commencement of the totality, and estimated its extreme breadth at half the moon's diameter, the brightness being greatest near the moon's limb, and gradually decreasing outwards. The phenomena of the red protuberances, witnessed by Mr. Dawes, are so clearly and satisfactorily described by him, that we think it best here to give the account of them in his own words:—

"Throughout the whole of the quadrant, from north to east, there was no visible protuberance, the corona being uniform and uninterrupted. Between the east and south points, and at an angle of about 170° from the north point, appeared a large red prominence of a very regular conical form, fig. 18. When first seen, it might be about $1\frac{1}{2}'$ in altitude from the edge of the moon, but its length diminished as the moon advanced.

"The position of this protuberance may be inaccurate to a few degrees, being more hastily noticed than the others. It was of a deep rose colour, and rather paler near the middle than at the edges.

"Proceeding southward, at about 145° from the north point commenced a low ridge of red prominences, resembling in outline the tops of a very irregular range of hills. The highest of these probably did not exceed 40″. This ridge extended through 50° or 55°, and reached, therefore, to about 197° from the north point, its base being throughout formed by the sharply-defined edge of the moon. The irregularities at the top of the ridge seemed to be permanent, but they certainly appeared to undulate from the west towards the east; probably an atmospheric phenomenon, as the wind was in the west.

"At about 220° commenced another low ridge of the same character, and extending to about 250°, less elevated than the other, and also less irregular in outline, except that at about 225° a very remarkable protuberance rose from it to an altitude of 1½′, or more. The tint of the low ridge was a rather pale pink; the colour of the more elevated prominence was decidedly deeper, and its brightness much more vivid. In form it resembled a *dog's tusk*, the convex side being northwards, and the concave to the south. The apex was somewhat acute. This protuberance, and the low ridge connected with it, were observed and estimated in height towards the end of the totality.

"A small double-pointed prominence was noticed at about 255°, and another low one with a broad base, at about 263°. These were also of the rose-coloured tint, but rather paler than the large one at 225°.

"Almost directly preceding, or at 270°, appeared a bluntly triangular pink body, *suspended*, as it were, in the corona. This was separated from the moon's edge when first seen, and the separation increased as the moon advanced. It had the appearance of a large conical protuberance, whose base was hidden by some intervening soft and ill-defined substance, like the upper part of a conical mountain, the lower portion of which was obscured by clouds or thick mist. I think the apex of this object must have been at least 1′ in altitude from the moon's limb when first seen, and more than 1½′ towards the end of total obscuration. Its colour was pink, and I thought it paler in the middle.

"To the north of this, at about 280° or 285°, appeared the most wonderful phenomenon of the whole. A red protuberance, of vivid brightness and very deep tint, arose to a height of, perhaps, 1½′ when first seen, and increased in length to 2′, or more, as the moon's progress revealed it more completely. In shape it somewhat resembled a *Turkish cimeter*, the northern edge being convex, and the southern concave. Towards the apex it bent suddenly to the south, or upwards, as seen in the telescope. Its northern edge was well defined, and of a deeper colour than the rest, especially towards its base. I should call it a *rich carmine*. The southern edge was less distinctly defined, and decidedly paler. It gave me the impression of a somewhat conical protuberance, partly hidden on its southern side by some intervening substance of a soft or flocculent character. The apex of this protuberance was paler than the base, and of a purplish tinge, and it certainly had a flickering motion. Its base was, from first to last, sharply bounded by the edge of the moon. To my great astonishment, this marvellous object *continued visible for about five seconds*, as nearly as I could judge, *after the sun began to reappear*, which took place many degrees to the south of the situation it occupied on the moon's circumference. It then rapidly faded away, *but it did not vanish instantaneously*. From its extraordinary size, curious form, deep colour, and vivid brightness, this protuberance absorbed much of my attention; and I am, therefore, unable to state precisely what changes occurred in the other phenomena towards the end of the total obscuration.

"The arc, from about 283° to the north point, was entirely free from prominences, and also from any roseate tint."

36. Although the different parties of observers scattered over the path of the moon's shadow were not equally fortunate in having a clear unclouded sky, they were all enabled to observe and record the effects of the total obscuration upon the surrounding objects and country. Dr. Robertson of Edinburgh, Dr. Robinson of Armagh, and some others, witnessed the eclipse from an island off the coast of Norway, in lat. 61° 21′, at a point in the path of the axis of the shadow. The precursory phenomena corresponded with those described by other observers. The atmosphere was, however, obscured by clouds, which appeared to rush down in streams from the place of the sun. The sea-fowl flocked to their customary places of rest and shelter in the rocks. The darkness at the moment of total obscuration was sudden, but not absolute; for the clouds had left an open strip of the sky, which assumed a dark lurid orange, which changed to greenish colour in another direction, and shed upon persons and objects a faint and unearthly light. Lamps and candles, seen at fifty or sixty yards' distance, were as visible as in a dark night, and the redness of their light presented a strange contrast with the general green hue of everything around them. "The appearance of the country," says Dr. Robertson, "seen through the lurid opening under the clouds, was most appalling. The distant peaks of the Tostedals and

Dorieffeld mountains were seen still illuminated by the sun, while we were in utter darkness. Never before have we observed all the lights of heaven and earth so entirely confined to one narrow stripe along the horizon,—never that peculiar greenish hue, and never that appearance of outer darkness in the place of observation, and of excessive distance in the verge of the horizon, caused in this case by the hills there being more highly illuminated as they receded, by a less and less eclipsed sun."

Mr. Hind says, that during the obscuration "the entire landscape was overspread with an unnatural gloom; persons around him assumed an unearthly cadaverous aspect; the distant sea appeared of a lurid red; the southern heavens had a sombre purple hue, the place of the sun being indicated only by the CORONA; the northern heavens had an intense violet hue, and appeared very near. On the east and west of the northern meridian, bands of light of a yellowish crimson colour were seen, which gradually faded away into the unnatural purple of the sky at greater altitudes, producing an effect that can never be effaced from the memory, though no description could give a just idea of its awful grandeur."

At several places in Prussia, where the heavens were unclouded during the total obscuration, a great number of the more conspicuous stars, as well as the planets Jupiter, Venus, and Mercury, were visible. Several flowering plants were observed to close their blossoms, birds which had been previously flying about disappeared, and domestic fowls went to roost.

37. Many of the phenomena attending total solar eclipses afford strong corroboratory evidence of the existence of a solar atmosphere, extending to a vast height above the luminous coating of the sun.

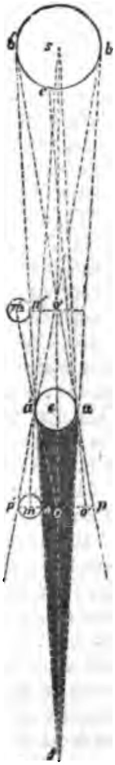
The corona, or bright ray or glory, surrounding the dark disc of the moon where it covers the sun, is observed to be concentric with the moon only at the moment when the latter is concentric with the sun. In other positions of the moon's disc, it appears to be concentric with the sun. This would be the effect produced by a solar non-luminous atmosphere faintly reflecting the sun's light.

38. It appears to be agreed generally among astronomers that the red emanations above described are solar, and not lunar. If they be admitted then to be solar, it is scarcely possible to imagine them to be solid matter, notwithstanding the apparent constancy of their form in the brief interval during which at any one time they are visible, for the entire duration of their visibility has never yet been so much as four minutes. To admit the possibility of their being solar mountains projecting above the luminous atmosphere surrounding the sun, and rising to the height

in the exterior and non-luminous atmosphere forming the corona necessary to explain their appearance, we must suppose their height to amount to nearly a twentieth part of the sun's diameter, that is to 44000 miles.

The fact that they are gaseous and not solid matter appears, therefore, to be conclusively established by their enormous magnitude, the great height above the surface of the sun at which they are placed, their faint degree of illumination, and the circumstances of their being sometimes detached at their base from the visible limb of the sun. These circumstances render it probable that these remarkable appearances are produced by cloudy masses of extreme tenuity, supported, and probably produced in an extensive spherical shell of non-luminous gaseous matter, surrounding and rising above the luminous surface of the sun to a great altitude.

Fig. 19.



LUNAR ECLIPSES.

39. As the earth moves in its orbit round the sun it projects behind it a conical shadow, the axis of which is always directed to that point of the heavens which is in immediate opposition to the centre of the sun. A section of the sun *s*, and the earth *e*, and of the conical shadow made by a plane passing through the centres of the sun and earth, is shown in fig. 19.

It will be evident whenever the globe of the moon or any part of it enters within the limits of the conical shadow *a f a'*, it will be deprived of the sun's light, and will consequently be eclipsed; the circumstances, therefore, which determine lunar eclipses will depend upon the transverse section of the shadow at the moon's distance from the earth, this distance being about one-third of the total length of the conical shadow.

It is found by calculation that its greatest apparent diameter, as seen from the earth, is 45′ 42″, and its least 37′ 49″. Its mean magnitude is, therefore, 41′ 45″.

40. The section of the shadow may, therefore, be regarded as a dark disc, whose apparent semi-diameter varies between 37′ 49″ and 45′ 42″, and the true place of whose centre is a point on the ecliptic 180° behind the centre of the sun. A lunar eclipse is

produced by the superposition, partial or total, of this disc on that of the moon, and the circumstances and conditions which determine such an eclipse are investigated upon the principles already explained.

41. By the solar tables, the apparent position of the centre of the sun, from hour to hour, may be ascertained, and the position of the centre of the section of the shadow may thence be inferred. From the lunar tables, the position of the moon's centre being in like manner determined, the distance between the centres of the section of the shadow and the moon's disc can be ascertained.

The magnitude of the eclipse is measured by the difference between the sum of the semi-diameters and the distance between the centres.

42. That a lunar eclipse may take place, it is necessary that the moon, when in opposition, should approach the ecliptic within a distance less than the sum of the apparent semi-diameters of the moon and the section of the shadow.

When the distance from the node at opposition is greater than 5° 44′ 21″, a total eclipse cannot, and when less than 3° 54′ 5″, it must, take place. Between these limits it may or may not occur, according to the magnitude of the parallaxes and apparent diameters.

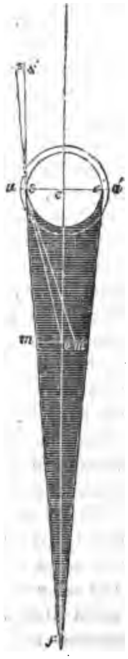
43. The duration of a total eclipse depends on the distance over which the centre of the moon's disc moves relatively to the shadow, while passing from the first to the last internal contact. This may vary from 0, to twice the greatest possible distance of the moon's centre from the centre of the shadow, at the moment of internal contact.

44. Long before the moon enters within the sides of the cone of the shadow it enters the penumbra, and is partially deprived of the sun's light, so as to render the illumination of its surface sensibly more faint. When once it passes within the line *a′ p′*, fig. 19, forming the external limit of the penumbra, it ceases to receive light from that part of the sun which is near the limb *b*. As it advances closer to *a′ f*, the edge of the true shadow, more and more of the solar rays are intercepted by the earth; and when it approaches the edge, it is only illuminated by a thin crescent of the sun, visible from the moon over the edge of the earth at *a′*. It might be thus inferred, that the obscuration of the moon is so extremely gradual, that it would be impossible to perceive the limitation of the shadow and penumbra. Nevertheless, such is the splendour of the solar light, that the thinnest crescent of the sun, to which the part of the moon's surface near the edge of the earth's shadow is exposed, produces a degree of illumination which contrasts so strongly with the shadow as to

render the boundary of the latter so distinct, that the phenomenon presents one of the most striking evidences of the rotundity of the earth, the form of the shadow being accurately that which one globe would project upon another.

45. If the earth were not surrounded with an atmosphere capable of refracting the sun's light, the disc of the moon would be absolutely invisible after entering within the edge of the shadow. For the same reason, however, that we continue to see the sun's disc, and receive its rays after it has really descended below the horizon, an observer placed upon the moon, and therefore the surface of the moon itself, must continue to receive the sun's rays after the interposition of the edge of the earth's disc as seen from the moon. This refracted light falling upon the moon after it has entered within the limits of the shadow, produces upon it a peculiar illumination, corresponding in faintness and colour to the rays thus transmitted through the earth's atmosphere.

Fig. 20.



To render this more clear, let *e e'*, fig. 20, represent a diameter of the earth at right angles to the axis *c f* of the shadow, and let *a a'* represent the limits of the atmosphere. Let *s e f* be the ray proceeding from the edge of the sun, and forming therefore the boundary of the shadow, considered without reference to the atmosphere. But the solar rays in passing through the convex shell of air, between *a* and *e*, are affected as they would be by a convex lens composed of a transparent refracting medium, and are therefore rendered convergent, so that the ray *s e*, instead of passing directly to *m*, will be bent inwards towards *m'*, while the ray which really passes from *e* to *f* is one which comes in the direction *s' e*, and therefore from a point within the sun's disc. The moon's disc, therefore, or any point of it which is within the angle *m e m'*, will receive this refracted light, and will be illuminated by it in accordance with its colour and intensity.

The deflection which a solar ray suffers in passing through the atmosphere towards *e* on the side of the sun, is equal to the horizontal refraction; and as, according to the principles of optics, it suffers an equal refraction in passing out on the other side, the total deflection, which is measured by the angle *m e m'*, is twice the horizontal refraction. But the mean value of the horizontal refraction being 33′, the mean value of the angle *m e m′* will be 66′. But since the greatest value of *m e o* is 45′ 42″, it follows that the refracted ray *e m′* will fall upon the section of the shadow at a point beyond its centre; and since the same will take place at all points round the shadow, it follows that the entire section will be more or less illuminated by the light thus refracted: the intensity of such illumination increases from the centre towards the borders.

46. When the moon's limb first enters the shadow at *m*, the contrast and glare of the part of the disc still enlightened by the direct rays of the sun render the eye insensible to the more feeble illumination produced upon the eclipsed part of the disc by the refracted rays. As, however, the eclipse proceeds, and the magnitude of the part of the disc directly enlightened decreases, the eye, partly relieved from the excessive glare, begins to perceive very faintly the eclipsed limb, which is nevertheless visible from the beginning in a telescope, in which it appears with a dark grey hue. When the entire disc has passed into the shadow, it becomes distinctly visible, showing a gradation of tints from a bluish or greenish on the outside to a gradually increasing red, which, further in, changes to a colour resembling that of incandescent iron when at a dull red heat. As the lunar disc approaches the centre of the shadow, this red line is spread all over it. Its illumination in this position is sometimes so strong as to throw a sensible shadow, and to render distinctly visible in the telescope the lineaments of light and shadow upon its surface.

These effects are altogether similar to the succession of tints developed in our atmosphere at sunset, and arise, in fact, from the same cause, operating, however, with a two-fold intensity. The solar rays traversing twice the thickness of air, the blue and green lights are more effectually absorbed, and a still more intense red is imparted to the tints transmitted. Without pursuing these consequences further here, the student will find no difficulty in tracing them in the effects of sunset and of sunrise, and of evening and morning twilight.

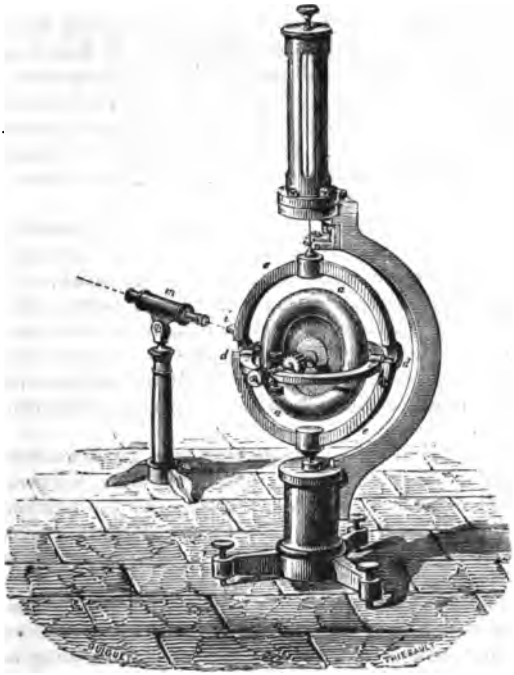


Fig. 4.

TERRESTRIAL ROTATION.

1.—Experimental demonstration by means of a pendulum invented by M. Leon Foucault.—2. Not more evident or conclusive than the diurnal motion of the firmament.—3. Effect of the experiment performed at either pole.—4. At equator. — 5. At other latitudes—6. Foucault's gyroscope.—Its application to demonstrate the earth's rotation.

1. In former parts of this series the various proofs upon which the fact of the diurnal rotation of the earth is established have been explained. Since, however, the ingenious experiments of M. Leon Foucault have, of late, invested the point with fresh popular interest, a brief analysis of the results of these may not be unacceptable to the readers of this series.

TERRESTRIAL ROTATION.

The diurnal rotation of the earth could obviously be rendered apparent, provided any line or plane could be found upon the earth's surface which would not participate in the motion of rotation, since in that case the relative position of all objects referred to such line or plane would be changed from hour to hour, as the earth turns upon its axis. It is upon this simple principle that the methods of illustration contrived by M. Leon Foucault have been based.

It must be first observed, that the rotation of a pendulous mass around the line of direction of the string by which it is suspended will not produce any change in the plane of vibration. This may be easily proved experimentally by imparting to the point of suspension of the pendulum a rotatory motion by which the wire or string suspending the pendulous mass can be made to revolve. The pendulum being put in vibration, it will be found that such motion of rotation will not in any way affect the plane of its oscillation.

If we suppose a pendulum to be suspended immediately over the north pole of the earth and put in vibration, the plane of its oscillation will not be affected, therefore, by the rotation which its point of suspension will, in that case, have in common with the earth. The earth will revolve under, while the plane of oscillation retains a fixed direction. The observer, meanwhile, being unconscious of the earth's rotation, the plane of oscillation will appear to him to have a motion of uniform rotation round the axis of suspension, one complete revolution being made in 23h. 56m. This rotation will moreover take place in the same direction as that in which the hand of a watch would move, or in which a right handed screw would be turned.

2. Such being the effect produced upon the observer, it is not quite correct to say that this experiment renders visible the rotation of the earth, since, in fact, it does not render that phenomenon more visible than does the apparent rotation of the firmament.

Ingenious, therefore, as M. Foucault's experiment incontestably is, I think its effect, considered as a popular demonstration of the earth's rotation, has been greatly misrepresented and exaggerated. It accomplishes nothing more than the artificial production of an apparent motion in an object which can by mathematical and physical reasoning be proved to be stationary, precisely in the same manner as, by mathematical and physical reasoning, the firmament can be proved to be stationary.

Nevertheless, as the experiment involves some mechanical considerations which are not uninstructive, it may be worth while to develop them more fully.

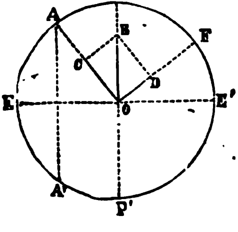
3. If the experiment be supposed to be performed at the north pole, the rotation of the earth being from west to east, the apparent motion of the pendulum consequent upon it will be from east to west, and will, as viewed by an observer placed over it, as already stated, have the direction of the motion of the hand of a watch.

If, however, it be performed at the south pole, the apparent motion, when viewed by an observer placed above it, being still from east to west, would appear to be contrary to that of the hand of a watch.

4. If the experiment were performed at the equator, the axis of the pendulum being in the plane of the equator, which is not affected in its position by the rotation of the earth, the plane of oscillation making always the same angle with the plane of the equator, no apparent rotation would take place, and, consequently, at the equator the experiment would afford no indication of the earth's rotation.

5. At any point between the equator and the poles the phenomena would be somewhat more complicated, and the analysis would require the application of more advanced mechanical principles. It is demonstrated in the higher mechanics, that the composition and resolution of rotatory motion is determined upon the same principles exactly, as those explained in the case of linear motion in the "Handbook of Mechanics," book ii. chap. i. Thus a rotatory motion, having a given angular velocity round a given axis, will be mechanically equivalent to two rotatory motions taking place simultaneously round two axes in the direction of the sides of a rectangular parallelogram, of which the axis of the primary rotation is the diagonal, and whose angular velocities are proportional to these sides. Thus, in fig. 1, if O B represent the rotatory motion of the earth round its polar axis, this rotatory motion is mechanically equivalent to two others, one round O C and the other round O D, at right angles to each other, the velocity of these respectively being to the velocity round the polar axis in the ratio of the lines O C and O D to the line O B.

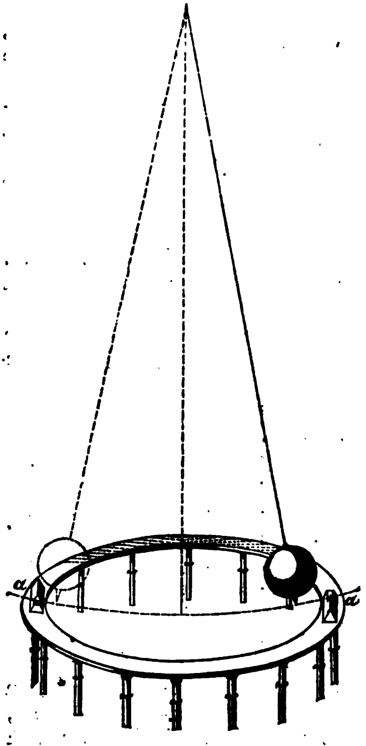
Fig. 1.



According to this principle, we may substitute for the rotation round the polar axis two simultaneous rotations—one round O A, with the velocity represented by O C, and the other round O F, with the velocity represented by O D.

To explain, then, the phenomena which would take place with reference to a pendulum suspended at any intermediate latitude A, between the pole P and the equator E, we have only to suppose, at a given moment, the earth to be affected simultaneously by two rotations, one round the axis O A, and the other round the axis O F. But, according to what has been explained already with regard to a pendulum placed at the equator, it is evident that the rotation round O F would produce no effect upon the plane of oscillation of the pendulum at A, inasmuch as A, relatively to F, would have the properties of the equator. We are, therefore, to conceive the pendulum oscillating at A to be affected just as it would be if A were the extremity of the polar axis, the velocity of rotation being less than that of the actual rotation of the earth in the proportion of O C to O B.

Fig. 2.



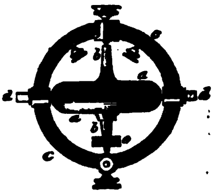
The effect therefore will be that the plane of oscillation of the pendulum will still revolve, as it would do at the pole, but with less and less velocity of rotation, according as the latitude is diminished.

The first experiments on this principle made by M. Foucault, took place in the Pantheon at Paris. An iron wire about 210 feet in length, was attached by its upper extremity to a metal plate fixed in the centre of the cupola of the building. It supported at its lower extremity a large and ponderous copper ball. When this pendulum was put in oscillation, it moved between its extreme limits very slowly, the time of oscillation being about 8 seconds. In order to render more sensible the rotation of the plane of oscillation round the axis of the pendulum, little mounds of sand, *a a*, fig. 2, were placed upon a circle formed round the axis of oscillation, and a point projecting from the ponderous ball struck at each oscillation the ridge of this mound, throwing off a small portion of the sand; and thus by the continued motion of the plane of oscillation, the top of the ridge was gradually cut off, leaving a flat surface instead of an angular edge as indicated in the figure.

6. M. Foucault has more recently contrived another form of experiment, by which the earth's rotation is demonstrated by exhibiting another apparent motion artificially produced by it. This second experiment is founded upon a principle of mechanics, in virtue of which a solid body, whose form is symmetrical with relation to a particular line, receiving a motion of rotation round that line, the direction of such axis of rotation will remain invariable whatever motion of translation may be imparted to the rotating body. If, therefore, it be so contrived that a body shall be thus put in rapid rotation round its axis of symmetry, and placed in circumstances so as not to be disturbed by the force of gravity, this body, while it is carried round with the diurnal rotation of the earth, will preserve the direction of its axis of rotation unchanged. While the direction of this axis therefore is fixed, the position of all bodies round it being continually changed by the rotation of the earth, an observer, unconscious of the change, will refer the motion to the axis itself; consequently that axis will appear to have such a motion, as would result from the relation between the bodies moved by the earth's rotation, and its own fixed direction.

M. Foucault realised this by an instrument to which he has given the name of *gyroscope*. A heavy metallic ring *a a*, figs. 3 and 4, is mounted upon an axis *b b*, which is fixed to its centre, and is perpendicular to its lateral faces. This disc, which is very massive, is so formed, that its matter shall be principally collected round its circumference, the central part being comparatively light. The axis *b b* is supported at its two extremities by two pivots round which the disc *a a* can turn freely. These two pivots are formed in a ring *c c* furnished with two knife-edges, like those upon which the beam of a balance is suspended. These knife-edges *d d* rest in cavities formed for them at two opposite points of the vertical ring *e e*. This ring itself is suspended by a wire of some length, which allows it to turn freely round the vertical line on which the wire is directed; and to prevent the wire with what it supports from receiving a pendulous motion from any disturbing

Fig. 3.



cause, the ring is furnished below with a fine point, which enters a hole large enough to allow it to turn freely without friction. This mode of suspension of the disc *a a*, and the axis *b b*, which is united with it, evidently allows the direction of the axis *b b* to vary in all possible ways. By making the ring *e e* turn round the vertical, which passes through the suspending wire and through the inferior point, the axis *b b* can be directed in any vertical plane whatever. In like manner, by making the ring *c c* turn upon the knife edges *d d*, the inclination of the axis *b b* can be varied at will, and these two motions can be produced without any sensible variation whatever.

This apparatus has been constructed with the most exquisite degree of perfection by M. G. Froment of Paris, so that the centre of gravity of the disc *a a* is precisely upon its axis of rotation, and the centre of gravity of the ring *c c* is found also exactly upon the axis of the two knife-edges *d d*. It follows from this, *first*, that gravity has no effect whatever upon the motion of rotation of the disc round its axis of symmetry; and *secondly*, that it cannot in any manner tend to vary the inclination of the axis *b b*, by making the ring *c c* turn round the line of suspension formed by the knife-edges.

To perform the experiment, the part of the apparatus which is represented separately in fig. 3 is taken off, and is placed on a machine adapted to impart to the disc *a a* an extremely rapid motion of rotation by means of the small-toothed pinion *o*. When the disc is thus put in rotation, it is again placed with the ring *c c* in the position indicated in fig. 4. The axis *b b* having thus the horizontal direction, makes an angle with the axis of the earth, and will consequently appear to be moved round this line; but this apparent motion can only be produced in so far as the ring *c c* turns by degrees round the knife-edges *d d*, and at the same time the vertical ring *e e* turns round the sustaining wire. This last movement can be observed by the aid of a microscope *m* placed near the apparatus, and directed to a small divided plate *i* which the ring *e e* carries. The divisions of this little plate pass one by one before the micrometer wires of the microscope absolutely in the same manner as stars are observed to pass before the micrometer wires of an astronomical telescope.

The apparent motion is obviously due to the rotation of the earth referred to the fixed direction of the axis of symmetry of the rotating ring.

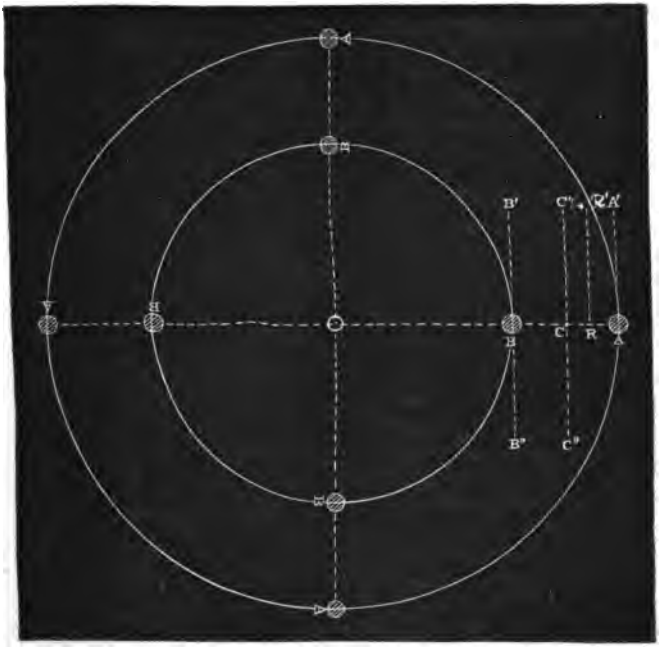


Fig. 1.

LUNAR ROTATION.

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1.—Necessity for a conclusive and popular proof.—2. Simplification of the conditions.—3. Demonstration by the principles of the composition of force and properties of couples.

1. SINCE the publication of our tract upon the Moon, the question so often raised as to the rotation of that body has been revived; and has obtained great publicity, and excited more than usual attention by being admitted for discussion in so widely circulated a journal as the "Times." From the discussion which has taken place, it appears sufficiently evident that, however conclusive the generally received demonstration of that motion may be to the minds of men of science in general, it not only has not brought conviction to the understanding of those who are not

familiar with mathematics, but has failed to do so to some who are admitted to have not inconsiderable mathematical attainments.

For these reasons I have applied myself to the discovery of a form of demonstration of the axial rotation, founded exclusively on the most elementary principles of geometry and mechanics, which I think it will be useful here to offer to the class of readers to whom these volumes are addressed.

To deal with the problem of rotation as applied to the moon itself, would necessarily involve very complicated and abstruse mathematical processes and formulæ, so technical as to be totally unintelligible to any except professed astronomers. I shall therefore at once strip the question of all this complexity by presenting it under its most general conditions, and divested of all those disturbing actions which are so well described by the Astronomer Royal as "pulling about the moon."

2. Let us suppose, then, a body to move in a circular orbit with an uniform motion round a centre of attraction, so that it shall in all positions present the same aspect to that centre; and let us further suppose that this system is free from the action of all disturbing forces exterior to it. In such case the revolving body will continue for an indefinite time to move in the same circular orbit round the centre of attraction, and will continue always to present the same aspect to that centre.

But in order still further to simplify the question, without in the least divesting it of those conditions the effects of which we seek for, let us suppose the body thus revolving to consist of two equal small masses A and B, (fig. 1.) connected by a rigid rod, which for greater simplicity we shall consider to be divested of inertia, and we shall suppose the bodies to be so placed that this connecting rod is directed to the centre O, round which the motion of revolution takes place. As A B revolves, therefore, the centres of the two small masses will describe concentric circles round O, and at the four quadrantal points of the circle the masses will assume the positions indicated in the figure.

3. We are now to demonstrate that under such circumstances the system A B will rotate uniformly round its centre C, making one complete rotation in the time which it takes to make one complete revolution round the centre O.

It is well understood in mathematical physics, that a point revolving in a circle is affected at once by two forces, one directed to the centre of the circle, and thence called the centripetal force, and the other directed along a tangent to the circle drawn through the place at which the point is moving, and called the tangential or projectile force. If the body be suddenly deprived of the action of either of these forces, it will immediately move in the direction of the other. If the central attraction be suddenly suspended, the body will move with the velocity it had in the circle, in the direction of the tangent to the circle drawn from the point at which the body was found, at the moment of the suspension of the central force.

This being admitted, let A A′ be a tangent to the circle in which A moves, and B B′ a tangent to the circle in which B moves. Let us suppose that when the revolving body has the position represented on the right of the figure, the central action towards O is suddenly suspended. In that case A will have a tendency to move in the direction of A A′ with the velocity with which it was previously moving, and B will in like manner have a tendency to move in the direction B B′ with its previous velocity. But the two masses being by the supposition connected by the rigid rod A B so as to form what in mathematical physics is called an invariable system, these two forces will be compounded, and their actual effect will be determined by the principles of the composition and resolution of forces.

To apply these principles, I shall have to use some mathematical symbols, which, however, I shall render as simple as possible.

$$\text{Let } \mathrm{C\,O} = \mathrm{R} \text{ and } \mathrm{C\,A} \text{ or } \mathrm{C\,B} = r.$$

Then we shall have,

$$\mathrm{O\,A} = \mathrm{R} + r \text{ and } \mathrm{O\,B} = \mathrm{R} - r.$$

Let A in revolving round O move in one second over a space which is the fractional part of the radius O A expressed by a. It is evident that the space moved over in one second by B will be the same fractional part of the radius O B. The velocity of A, or the space it moves through in one second, will then be $a\,(\mathrm{R} + r)$, and the velocity of B will in like manner be $a\,(\mathrm{R} - r)$.

Now, according to what has been explained, if we suppose the central attraction towards O to be suspended, the mass A will be affected by a force which will be found by multiplying the mass by the velocity $a\,(\mathrm{R} + r)$, and the mass B will in like manner be affected by a force found by multiplying the mass B by its velocity $a\,(\mathrm{R} - r)$. Since these masses are equal, let them be each expressed by m, and we shall have,

$$\text{force of A} = ma\,(\mathrm{R} + r)$$
$$\text{force of B} = ma\,(\mathrm{R} - r).$$

By the principles of the composition of parallel forces,* the resultant of those two forces will have an intensity equal to their sum,—that is, to $2ma\mathrm{R}$; and it will have a direction parallel to that of the components, and dividing the space between them in the inverse ratio of the forces, just as the fulcrum of a lever divides the space between the power and weight when these are in equilibrium.

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* See "Handbook of Mechanics," § 152, p. 42.

Let R R′ be the direction of this resultant, and let the distance R C be called x.

We shall then have,

$$\frac{ma\,(\mathrm{R}+r)}{ma\,(\mathrm{R}-r)}=\frac{r+x}{r-x}\quad\therefore\quad x=\frac{r^2}{\mathrm{R}}.$$

Thus the two forces, acting separately on A and B, are mechanically equivalent to a single force equal to $2ma\mathrm{R}$, acting at R in the direction of R R′.

Now, let us suppose two equal and contrary forces applied at C, each equal to $2ma\mathrm{R}$, one in the direction C C′, and the other in the direction C C″. Since these forces neutralise each other, they will not affect the system, and are merely introduced to serve the purposes of the demonstration.

The system is then under the operation of the three equal forces here following:—

1°——$2ma\mathrm{R}$ acting in the direction C C′
2°——$2ma\mathrm{R}$ acting in the direction C C″
2°——$2ma\mathrm{R}$ acting in the direction R R′.

But the last two form a combination called in mechanics a *couple.**

It is proved in mechanics that the effect of a couple depends on the direction of the plane which passes through its components, and on its moment. This moment is the product of the force of the components and the distance between their directions. The distance between their directions in this case being x, and the force being $2ma\mathrm{R}$, the moment of the couple is

$$2ma\mathrm{R}\,x=2\,mar^2.$$

Now, since all the couples which have the same moment and the same plane are mechanically equivalent, we may substitute for this couple another, of which the forces are mar applied at A and B in the directions A A′ and B B″. The moment of such a couple will be,

$$mar\times\mathrm{A\,B}=2\,mar^2,$$

and therefore obviously equivalent to the couple acting at C and R, for which it is substituted.

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* See "Handbook of Mechanics," §155, p. 44.

Let us now see the forces under the action of which the system is placed. They are as follows:—

1°——$2ma$R acting at C in the direction C C′
2°——mar acting at A in the direction A A′
3°——mar acting at B in the direction B B″.

The first acting at the centre of gravity C of the two masses A and B, will impart to the system an uniform motion of translation in the direction C C′ with the velocity ma, that is, the velocity with which C moved round O before the suspension of the central attraction.

The second and third acting at A and B with equal intensities, will have the same effect as the fingers would have applied to the opposite sides of a top or teetotum, causing the system to spin or rotate round C as a centre. The velocity with which A and B will move relatively to the centre C will be found by dividing the moving force mar by the mass, and will therefore be ar.

But that A and B should have the velocity ar, they must move in each second through an arc which is the fraction of the radius expressed by a. It follows, therefore, that the velocity with which the system would rotate round C as a centre, would be precisely the same as that with which it previously revolved round O.

Thus it appears that, by suppressing the central force which affected the system, two motions remained undestroyed: 1°, a motion of translation in the direction of the tangent to the orbit at the point where the central action was supposed to be suppressed, with an uniform velocity equal to that with which the centre of gravity, C, of the system previously revolved round the centre of attraction, O; and 2°, a motion of uniform rotation round C with such a velocity as to make one complete rotation in the time in which the system previously made a complete revolution round O.

Since it is evident that the mere suppression of the central attraction, cannot have imparted to the system any forces or motions with which it was not previously affected, it follows that it must have had those two motions while the central force was in operation, and that its actual motion then resulted from the combination of the three.

If, besides suspending the action of the central attraction, the centre of gravity, C, of the system, be supposed to be at the same moment fixed, then the motion of translation will be arrested as well as that of revolution, but the motion of rotation will remain unaffected, and the system will rotate round C as a fixed centre, making one complete rotation in the time it previously made one complete revolution round O.

It may be here observed that the ideas on the subject of revolution and rotation recently put forth are not limited to the moon, nor to any other globe of which the time of rotation is equal to that of revolution. They are equally applied to, and equally incompatible with, all the conclusions of astronomers as to the rotation of the earth and the other planets.

All the difficulty which some persons have found in comprehending this question seems to arise, from the several independent motions, at the same time affecting the same body, disguising each other. They do not, however, the less really exist. The tangential motion is disguised by its combination with the centripetal motion, and *vice versâ*, and both of these effects disguise the motion of rotation.

It is evident that the reasoning which we have here applied to the two connected masses, A and B, is, *mutatis mutandis*, applicable to all bodies placed on the surface of the earth, and sharing in its diurnal motion. All such bodies are in fact affected with a motion of rotation, as well as one of revolution, the former being imparted to them by their material connection with the earth. If the entire mass of the earth, except a mountain—the Peak of Teneriffe, for example—were suddenly annihilated, the mountain would rotate on an axis parallel to the terrestrial axis, and the time of its rotation would be equal to that of the globe.

To the objection, that no one is conscious of this motion of rotation, either in themselves or the objects around them, it may be answered, that the state of apparent quiescence arises from the common rotation, by which all bodies are affected, being disguised by its combination with other motions.

ASTRONOMICAL INSTRUMENTS.

1.—Astronomical observations.—2. Visual line.—3. Vertical and equatorial instruments.—4. Herschel's great telescope.—5. The lesser Rosse telescope.—6. The greater Rosse telescope.—7. Oxford heliometer.—8. Troughton's transit circle.—9. Greenwich transit circle.—10. Troughton's altitude and azimuth circle.—11. Greenwich altazimuth instrument.—12. Northumberland telescope.—Cambridge observatory.

1. All astronomical observation is limited either to ascertain the magnitudes, forms, and appearance of celestial objects, or to determine the places they occupy at any given moment on the firmament.

To attain the former object, telescopes are constructed with the greatest practicable magnifying and illuminating powers, and so mounted as to enable the observer with all the requisite facility to present them to those parts of the heavens in which the objects of his observation are placed.

2. To attain the latter, it is necessary to provide an apparatus by which the direction of the visual line of the object of observation relatively to some fixed line and some fixed plane can be ascertained. The visual line being the straight line drawn from the eye of the observer to the object, at the moment of the observation, and having, therefore, no material, tangible or permanent existence, by which it can be submitted to measurement, it is necessary to contrive some material line with which the visual line shall coincide. The telescope supplies an easy and exact means of accomplishing this. When it is directed so that the object or its centre, if it have a disc, is seen upon the intersection of the middle wires in the eye-piece, the visual direction of the object is the line drawn from the centre of the object-glass of the telescope to the intersection of the middle wires.

3. Now the telescope being attached to a graduated circle is so placed, that the line joining the centre of the object-glass with the intersection of the wires is parallel to a diameter of the circle. This diameter will therefore be the direction of the visual line.

If the circle thus arranged be so mounted that a line drawn from the observer to the fixed point of reference, whatever that point be, shall be parallel also to a diameter of the circle, and if the circle be so mounted that, however its position may otherwise be changed, one of its diameters shall always pass through the fixed point of reference, the angular distance of the object of observation from the fixed point of reference will always be equal to the angle formed by the two diameters of the circle, one of which is parallel to the line joining the centre of the object-glass, with the intersection of the wires at the moment of the observation, and the other parallel to the line drawn from the observer to the fixed point of reference.

But this is not yet enough to determine in a definite manner the position of the object on the heavens. A great many different objects may have the same angular distance from the fixed point of reference. If a plane be imagined to pass at right angles to a line drawn from the observer to the fixed point of reference, it will intersect the celestial sphere in a certain circle, every point of which will obviously be at the same angular distance from the point of reference. To render the position of the object of observation determinate, it is therefore necessary to know the position of the plane of the graduated circle, with relation to a circle whose plane is at right angles to that diameter of the celestial sphere which passes through the fixed point of reference.

The plane of the graduated circle may be fixed or movable. If fixed, its position with relation to the fixed point of reference is ascertained once for all; after which, the position of the object of observation will be determined merely by its angular distance from the point of reference. If movable, it is necessary to provide another graduated circle, the plane of which is perpendicular to the first, and upon which some fixed direction is marked. The position of the plane of the movable circle, which carries the telescope, with relation to this latter fixed direction, is then ascertained by the arc of the second graduated circle, which is included between the movable circle and such fixed direction.

All instruments of observation for determining the position of objects on the celestial sphere are constructed and mounted on one or other of these principles; and they differ one from another in respect to the point adopted as the fixed point of reference, and the plane at right angles to the diameter of the sphere passing through that point with relation to which the position of the circle, if it be movable, is determined.

The fixed point of reference is, in all cases, either the zenith or the pole; and the plane of reference, consequently, either that of the horizon or the equator.

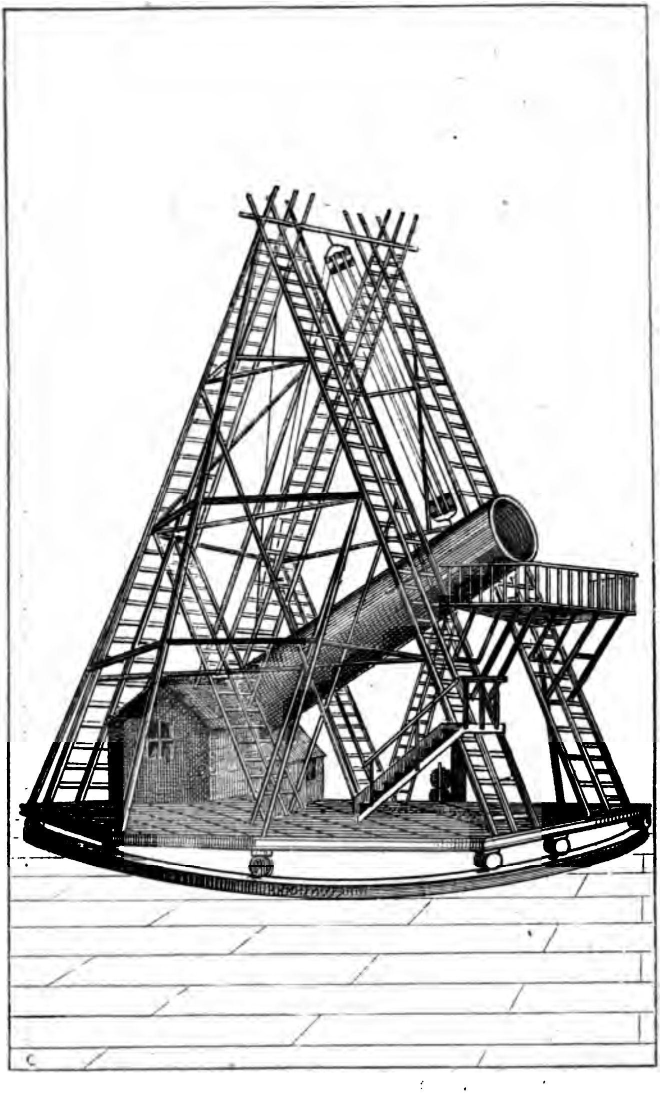
When the plane of the graduated circle carrying the telescope is fixed, it is almost invariably that of the meridian, but in certain instances, the circle has been fixed in the vertical plane at right angles to the meridian, that is to say, in the plane of the prime vertical.

When the fixed point of reference is the zenith, and the graduated circle is movable, the immediate results of the observations made with the instrument are the zenith distance or altitude and the azimuth of the object observed. Such instruments are, consequently, denominated ALTITUDE and AZIMUTH CIRCLES, or ALT-AZIMUTH INSTRUMENTS.

When the fixed point of reference is the pole, and the graduated circle is movable, the immediate results of the observations made with the instrument are the polar distance or declination and the right ascension of the object observed; and the motion of the instrument being parallel to the celestial equator, it is called an EQUATORIAL.

These general principles being understood, we shall give a few examples of each class of instrument, commencing with those which are adapted to the investigation of the magnitude, appearance, and structure of the celestial objects, without reference to their exact position in the firmament.

4. *Sir W. Herschel's forty-feet reflector.*—This instrument, is memorable as the first ever constructed upon a scale of such stupendous magnitude, and still more so for the vast discoveries made with it by its illustrious inventor and constructor. The instrument is mounted on a platform which revolves in azimuth on a series of rollers. The telescope is placed between four ladders, which serve the double purpose of a framework for its support and a convenient means of approaching the superior end of the great tube. These ladders are united at the top by being bolted to a cross bar, to which the pulleys are attached. By one system of pulleys, the telescope is raised or lowered; and by another the gallery or balcony in which the observer stands is also raised or lowered, so as to enable him to look into the tube. These pulleys are each worked by a windlass established on the platform below. The framing is strengthened by another system of diagonal ladders, as well as various masts and braces which appear in the figure. The telescope is so mounted that it can be raised until its axis is vertical, so that an object in the zenith can be observed with it. The observer's gallery rests in grooves upon the ladders, and slides up and down easily and smoothly by the operation of the pulley, so that when the telescope tube is elevated, even to the zenith, the observer can ascend and descend at pleasure by signals given to the man at the windlass. A small



SIR W. HERSCHEL'S 40-FOOT TELESCOPE.

staircase is placed near the foot of one of the principal ladders, by which observers can mount into the gallery when it is let down to its lowest point.

5. The total length of the telescope tube is 39 ft. 4 in., and its clear diameter 4 ft. 10 in. It is constructed entirely of iron. The great speculum is placed in the lower end of the tube, the apparatus for adjusting it being protected by the wooden structure which appears in the figure. The diameter of the speculum is 4 ft., and the magnitude of its reflecting surface is consequently 12·566 square feet. It contains 1050 lbs. of metal.

The axis of the speculum, when placed in the tube, is so inclined to the tube that its focus is at about two inches from the lower edge of the upper mouth of the tube, so that the observer, standing in the gallery with his back to the object, and looking over the edge of the tube towards the speculum, can direct an eye-piece conveniently mounted at that point upon the image of the object of observation formed by reflection in the focus.

Three persons are employed in conducting the observations: the observer, who stands in the gallery; his amanuensis, who may either be in the gallery or in the wooden house below, receiving the dictation of the observer by a speaking-tube; and the person who works the windlass.

6. *The great Rosse telescope.*—This stupendous instrument of celestial investigation, by far the largest and most powerful ever constructed, is represented at the head of p. 1, vol. i. of the Museum. The clear aperture is 6 ft., and consequently the magnitude of the reflecting surface is 28·274 square feet, being greater than that of Herschel's great telescope in the ratio of 7 to 3. It is at present used as a Newtonian telescope, that is to say, the rays proceeding along the axis of the great speculum are received at an angle of 45° upon a second small speculum, by which the focus is thrown towards the side of the tube where the eye-piece is directed upon them. Provision is, however, made to use the instrument also as an Herschelian telescope.

The great tube is supported at the lower end upon a massive universal joint of cast-iron, resting on a pier of stone-work buried in the ground, and is so counterpoised as to be moved with great ease in declination. In all such instruments, when it is required to direct them to an object, they are first brought to the desired direction by some expedient capable of moving them more rapidly, and they are afterwards brought exactly upon the object by a slower and more delicate motion. In this case, the quick motion is given by a windlass, worked upon the ground by an assistant at the command of the observer. The slow motion is imparted by a mechanism placed under the hand of the observer.

The extreme range of the telescope in right ascension, when directed to the equator, is 1 hour in time, or 15° in space; but when directed to higher declinations, its range is more extensive.

The tube is slung entirely by chains, and is perfectly steady, even in a gale of wind. When presented to the south, it can be lowered until it is nearly horizontal; towards the north, it can only be depressed to the altitude of the pole.

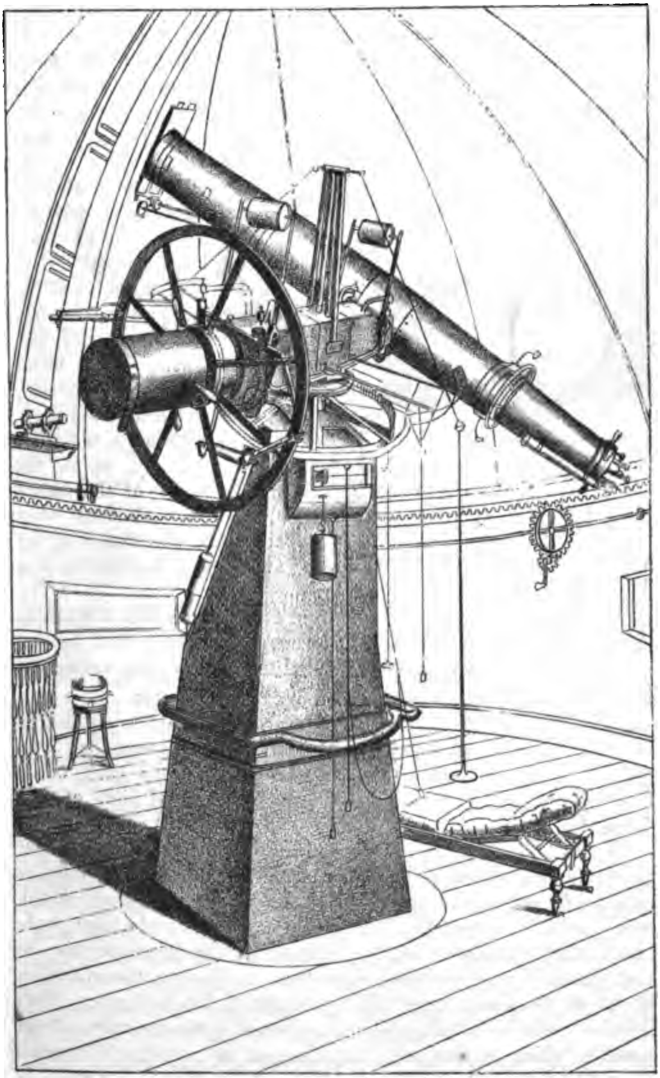
Two specula have been provided for the telescope, one of which contains 3½, and the other 4 tons of metal, the composition of which is 126 parts in weight of copper to 57½ of tin. The great tube is of wood hooped with iron, and is 7 feet diameter, and 52 in length. The side-walls, 12 feet distant from the tube, are 72 feet in length, 48 feet in height on the outside, and 56 feet in the inside. These walls are built in the plane of the meridian.

The observer stands in one or other of four galleries, the three highest of which are drawn out from the western wall, while the fourth or lowest has for its base an elevating platform, along the surface of which a gallery is moved from wall to wall by a mechanism at the command of the observer.

7. *The Oxford heliometer.*—This class of instrument, which derives its name from having been first applied to the measurement of the diameter of the sun, consists of a telescope equatorially mounted, the object-glass of which is divided along a plane passing through its optic axis, each half of the lens being capable of being moved in its own plane, so that the axes of the two semi-lenses, being always parallel to each other and to the axis of the telescope, may be within certain limits separated from each other, more or less, at the pleasure of the observer.

The polar axis, round which the instrument turns in right ascension, is fixed upon the face of a block of Portland stone, and the graduated circle measuring right ascension is seen at the top and at right angles to the polar axis. This circle receives its motion from clock-work. Rods are provided by which the observer can, at pleasure, set the clock going, or stop it, and connect it with, or disengage it from, the equatorial circle. The circle for indicating polar distance or declination is placed upon the horizontal axis of the instrument.

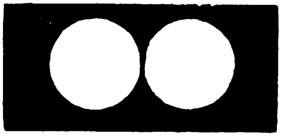
The object-glass of this instrument, sometimes called the "divided object-glass micrometer," supplies a very accurate method of measuring angles which do not exceed a certain limit of magnitude. It appears by the principles of optics, that when the image of a distant object is produced by a lens, *each point* of such image is formed by rays which proceed from *every point* of the lens. If, therefore, a part of the lens be covered by an opaque body or cut away, *each point* of the image will still



THE OXFORD HELIOMETER.

be formed by the rays which proceed from *every point of the lens which is not covered or cut away.*

It follows, therefore, that half a lens will produce at the focus an image of a distant object, and if two halves of the same lens be placed concentrically, they will form two images, the exact superposition of which will, in fact, constitute the image formed by the complete lens. But if the two halves be not concentrical, the two images will not be superposed, but will be separated by a space corresponding with, and proportional to, the distance between the centres of the two half lenses. Let the two half lenses be first placed concentrically, so that the two images shall be exactly superposed. Then let one of the two lenses be moved (the edges of the semi-lenses being always maintained in contact), until the image, formed by the semi-lens, which is moved, shall be removed to such a position that the two images shall touch each other externally, as in the figure. In that case it is evident that the centre of the image formed by the semi-lens which has been moved, must have moved over a space equal to the diameter of the image of the disc, and if the angular value of such space be known, the diameter of the object will be known.



The first application of the divided object-glass was to measure the apparent diameter of the sun, whence its name. The instrument, however, has since been applied to so many other important purposes, that the name has ceased to express its uses.

It is obvious, that the same principle will be applicable to measure the apparent angular distance between any two objects, such as two stars, which are so near each other that they may be seen together in the field of view of the telescope.

In this heliometer a very ingenious contrivance is introduced to enable the observer to read the scale by which the angular magnitude corresponding to the separation of the centres of the semi-lenses is indicated. This is accomplished by placing a scale behind the object-glass in the interior of the telescope tube, so that it can be read by means of a long microscope, the eye-glass of which is placed near the eye-piece of the telescope. This interior scale is illuminated by a piece of platinum wire placed near it, which is rendered incandescent by a galvanic current transmitted upon it at pleasure by the observer. This current is produced by a Smee's battery placed in a room below that containing the heliometer.

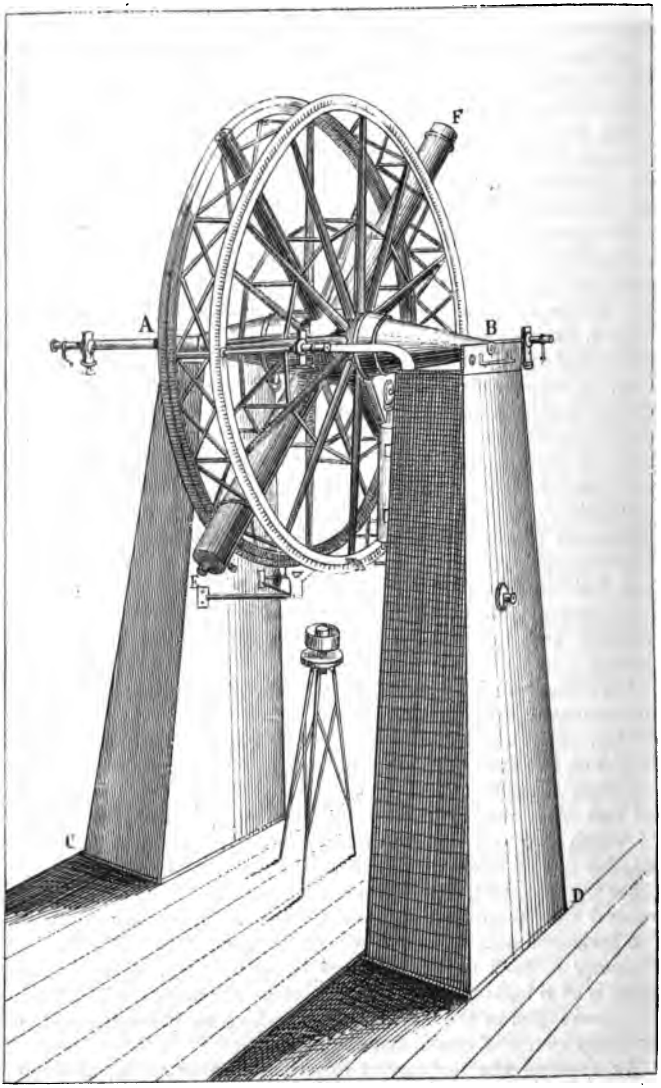
A very splendid instrument of this class has been erected at the Pultowa observatory.

8. *The transit circle by Troughton.*—This instrument unites the functions of the mural circle and the transit instrument. The telescope is fixed between two parallel flat metallic circles or rings, the exterior face of each of which is graduated to 5′. These flat rings are connected with the horizontal axis, by two sets of radial hollow cones, so as to form two wheels, and they are connected with each other by various bars, crossing each other so as to form rhomboidal figures, as well as by a system of perpendicular rods, which appear in the figure. Each of these rings is 4 feet in diameter. The horizontal axis, which receives the spokes of each of the wheels, is cylindrical between the wheels, the parts projecting beyond them being strong cones, which rest in Ys fixed on two piers of solid stone-work, 5 feet 6 in. in height, and a little less than 3 feet apart. The length of the horizontal axis is 3 feet. The faces of the stone piers coincide with the plane of the meridian, and the Ys are provided with adjustments, one of which is capable of raising and lowering the Y, and the other of moving it horizontally through small spaces.

9. *The Greenwich transit circle.*—The great mural circle and the transit instrument have lately been superseded at the Royal Observatory, Greenwich, by an instrument upon the principle of that just described, but constructed upon a vast scale of magnitude, and combined with a variety of accessories by which its stability and the necessary precision of its indications are secured.

Like the transit circle of Troughton, already described, this instrument consists of a telescope fixed between two parallel circles, one of which is graduated, resting on horizontal supports, placed on two stone piers, so that the line of collimation moves in the plane of the meridian. The telescope tube, which is nearly 12 feet long, consists of a hollow cube of metal, at the centre of which two cones are bolted by means of flanges. At the smaller end of one cone is the object-glass, and in that of the other the eye-piece. Each of these cones weighs 1·75 cwt. and the central cube with its pivots weighs 8 cwt. The whole length of the horizontal axis on which the instrument rests is 6 feet, the diameter of each of the bearings being 6 inches. The object-glass is of 8 inches aperture, its optical power being sufficient for the observation of the faintest objects which are presented in the ordinary course of meridional observations.

In erecting the instrument experiments were made, with the view of determining the amount of drop produced by the weight of the cones of the telescope, when it was found that this quantity



TROUGHTON'S TRANSIT CIRCLE.

did not exceed the thousandth of an inch. The parallel circles between which the telescope is fixed, are each 6 feet in diameter, and are firmly attached to cylindrical bands, one on each side of the central cube of the telescope. The clamping apparatus is applied to the eastern circle, and the western circle is graduated. The reading-off is effected by means of six microscopes, each 45 inches in length.

The graduation of the circle is such as to show approximately zenith distances; while a pointer fixed to a block projecting from the lower part of the pier directed to another graduated band on the outer or eastern side of the circle, is used for setting the telescope, and gives approximately north polar distances. A small finder, with a large field of view, is attached to the side of the cone near the eye-piece, as well as sights for directing the telescope to stars by the naked eye. A large gas-light conveniently placed illuminates, by means of reflectors, the graduated arc of the circle at the points where the several microscopes are fixed, and also the field of the telescope.

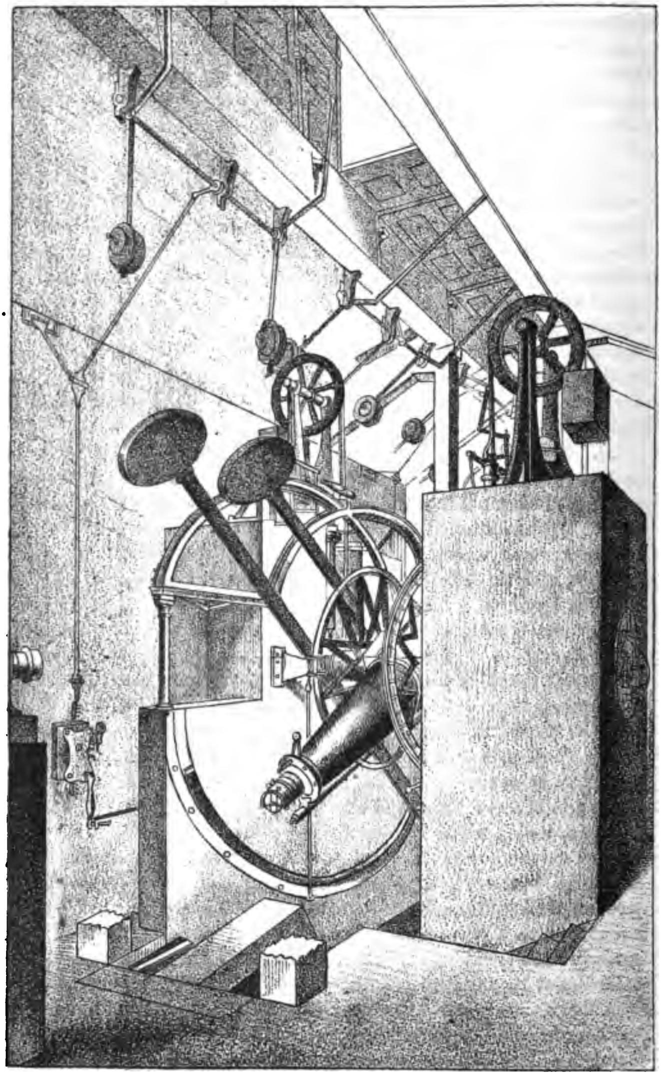
10. *Troughton's altitude and azimuth circle.*—The form of instrument best adapted to render the principle of altitude and azimuth instruments in general intelligible, is that which is shown in the annexed figure.

The drawing presents the circle so that all the important parts of it are visible. The instrument is supported on the capstone of a strong stone pedestal. Upon this, the fixed parts of the instrument, upon which it revolves in azimuth, are firmly established. They consist of a solid vertical cone, terminating below in an hexagonal solid mass of metal, each vertical face of which measures 3 inches square. From this proceed four radial cones, three of which, at angles of 120° with each other, are supported, on the stone pedestal, by feet supplied with adjusting screws, by means of which the instrument is levelled. The fourth radial cone, which forms an angle of 60° with two of the others, carries a clamp, which will be presently noticed.

The movable part of the instrument terminates at the lower part in a hollow cone, which appears in the figure between the two vertical pillars, with which it is connected by a metallic collar. This hollow cone rests upon and conceals the solid cone already described, and, turning freely upon it, gives to the instrument its azimuth motion.

A horizontal circle, 3 feet in diameter, is connected by conical spokes, in the usual manner, with the lower ends of the two vertical pillars and the intermediate hollow cone.

To the three radial cones of the fixed base of the apparatus, at angles of 120°, are attached three pieces, which rise vertically



GREENWICH TRANSIT CIRCLE.

outside the circle, and support three microscopes, by which the azimuthal angles are read off. This position for the microscopes gives some practical advantage, inasmuch as the observation is read at six different points of the limb, when the observation is repeated by turning the circle 180° in azimuth. To the fourth radial arm of the fixed base a clamp is attached, by which the position of the instrument is maintained in the position it has at the moment the observation is made. This clamp appears in the drawing with its tightening screw above it, and its tangent screw for giving the azimuth circle a slow motion to bring the instrument to its exact position. This tangent screw terminates in a square, which can be inserted in a square hole of corresponding magnitude, connected by an universal joint with a rod of convenient length, which the observer holds at the moment of the observation, and by turning which the whole instrument is moved slowly in azimuth.

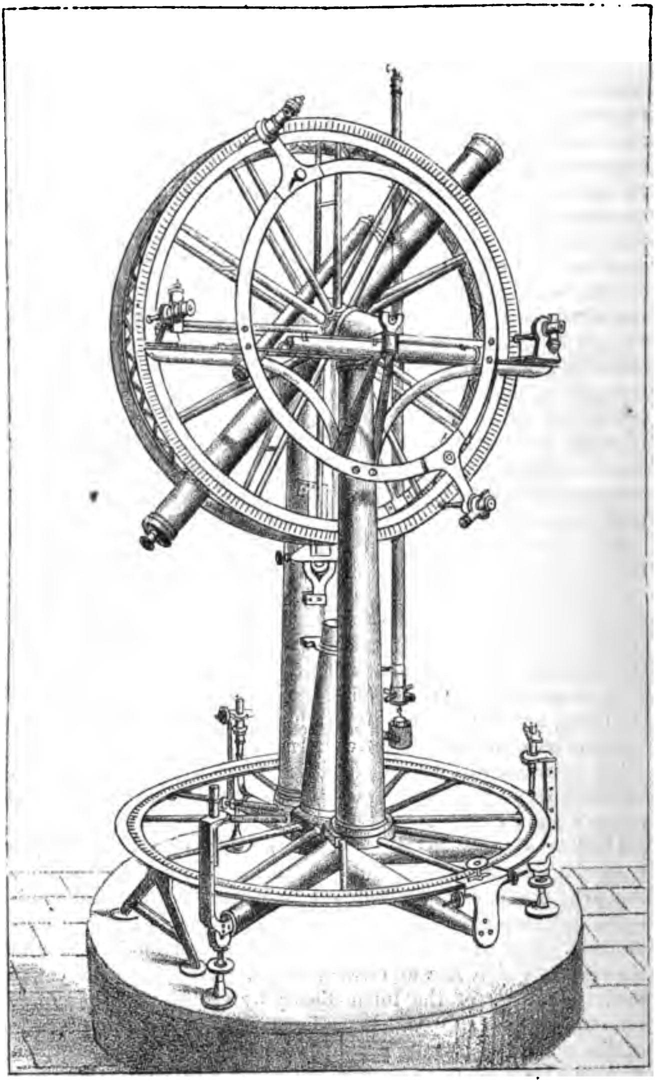
The vertical circle consists of two parallel limbs, having the telescope between them, constructed and connected in a manner exactly similar to the transit circle already described; and this circle is supported on the two vertical pillars in the same manner exactly, as already described in the case of the transit circle.

One only of the two vertical circles is graduated, being divided as well as the horizontal circle to 5′. The clamp, with its tangent screw, is placed on the side not graduated. The focal length of the telescope is 44·4 inches, and its aperture 3¼ inches.

The observations of altitude are read off by four microscopes, the supports of which are shown in the figure. Two are supported by arms attached to the vertical pillar on the graduated side of the circle, and the other two to a hoop screwed on the pillar and to the arms which carry the two former.

The instrument is provided with a plumb-line and four levels, by which its proper position with relation to the vertical direction can be always verified.

11. *The Greenwich alt-azimuth instrument.*—This, as the name imports, is an altitude and azimuth circle in principle similar to that just described, but in its construction and application different from any instrument of its class hitherto constructed. The purpose chiefly to which it is applied, and with the view to which it was conceived by the Astronomer Royal, is the improvement of the lunar theory by multiplying in a large ratio the observations which can be made from month to month on the moon, without in any degree impairing their precision. Such observations were always made with the mural circle and the transit, until this instrument was brought into operation, and they were consequently confined to the meridional transits of the



TROUGHTON'S ALTITUDE AND AZIMUTH CIRCLE.

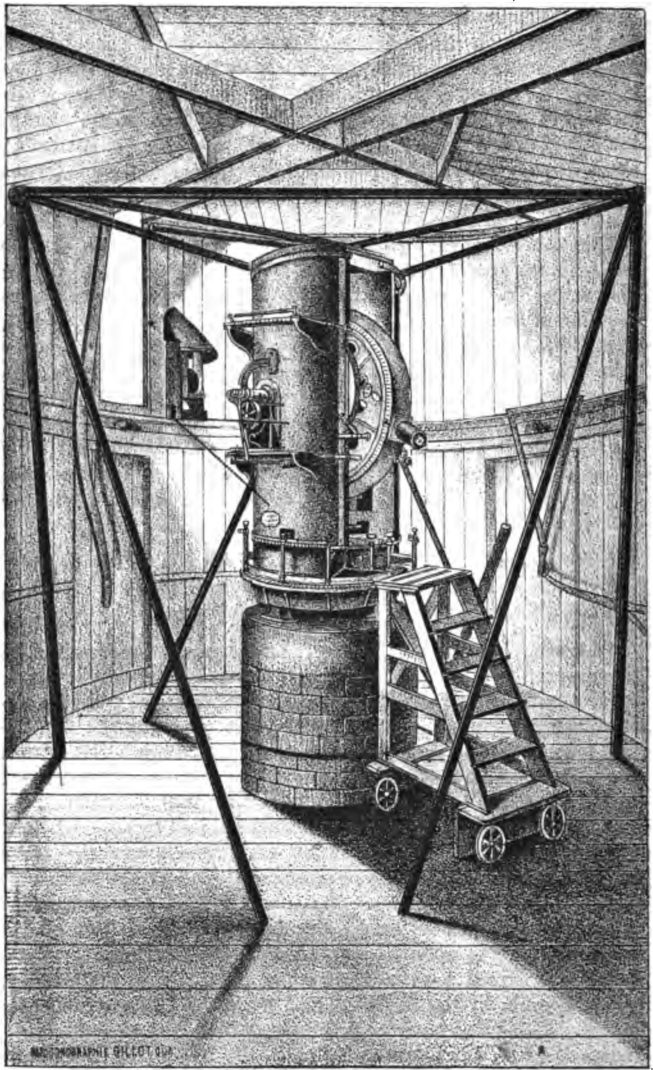
moon. Now, these transits cannot be observed, even when the firmament is unclouded, for four days before and four days after the new moon, in consequence of the proximity of that body to the sun; an interval amounting to little less than one-third of the month. Besides this, it happens in this climate, that, at the moment of the meridional transits at other parts of the month, the observation is frequently rendered impracticable by a clouded sky. It was, therefore, highly desirable to contrive some means of making the observations in extra-meridional positions of the moon.

This could obviously be accomplished by means of an altitude and azimuth circle, such as that described above; but such an instrument, however perfect might be its construction, is not susceptible of the necessary precision. The Astronomer Royal, therefore, conceived the idea of an instrument on the same principle, which, while it would be capable of shifting its azimuth, would still be susceptible of as much precision in each vertical in which it might be placed, as the mural circle has in the meridian. He accordingly proposed to attain this object by adopting adequate engineering expedients to produce the necessary solidity and invariability of form. He adopted as fundamental principles of construction,—

1. To produce as many parts as possible in a single casting;
2. To use no small screws for combining the parts;
3. To allow no power of adjustment anywhere.

Following out these principles, the instrument represented in the annexed figure was constructed, under his superintendence, by Messrs. Ransome and May, engineers, of Ipswich; the graduation being executed by Messrs. Troughton and Simms; and the first observation with it was made by Mr. Hugh Breen, jun., one of the assistants at the Observatory, on the 16th of May, 1847, which was found to be as good as any succeeding observation.

The instrument is mounted in a tower, raised to such a height as to command the horizon in all directions above the other buildings of the Observatory, except on the side of the south-east dome and the octagon room. The foundation of the instrument is a three-rayed pier of brickwork, carried up nearly to the level of the floor of the room appropriated to the instrument. Upon this pier is placed a cylindrical stone pillar, 3 feet in diameter, which appears in the drawing, and on which the instrument is placed. This pillar and the pier upon which it reposes are quite independent of, and unconnected with, the tower within which it is erected, and no not even touch the floor of the room through which they pass.



GREENWICH ALT-AZIMUTH INSTRUMENT.

THE GREENWICH ALT-AZIMUTH INSTRUMENT.

The fixed horizontal azimuth circle is solidly established upon this stone pillar. It is a circle 3 feet in diameter, the rim being connected with the centre in the usual way by spokes. The whole is constructed of hard gun-metal. In the upper surface of the rim a circular groove is left, which is filled with a band of silver, on which the divisions are engraved. This circle is divided into arcs of 5′ continuously from 0° to 360°. It is set with the zero towards the north, and the numbering of the divisions runs from north to east, south and west. This azimuthal circle was cast in a single piece, and weighs 441 lbs.

Attached to this, and concentric with it, is another fixed horizontal circle, having teeth on the inside edge, in which the pinions work by which the azimuth motion is given to the instrument.

There are four microscopes placed at equal distances over the graduated arc, which are provided with micrometers, by which the observation in azimuth is read off. These microscopes are attached to the instrument so as to revolve with it. Their reflectors are illuminated by a lamp properly placed.

The lower pivot on which the instrument turns, is supported on a point in the stone pillar at the centre of the azimuthal circle. To support the upper pivot, an iron triangle is established on the three-rayed pier. On each side of this, is erected another iron triangle, whose plane is vertical, and whose sides unite in a vertex which forms one of the angles of a corresponding triangle above. This upper triangle supports three radial bars, which carry at their point of union the Y in which the upper pivot plays. The bars of the lateral triangles, which are apparent in the drawings, pass the holes in the floor without touching it.

The frame, revolving in azimuth and carrying the instrument with it, consists of a top and bottom connected by vertical cheeks, all of cast-iron. The supports of the four microscopes for reading off the azimuth on the lower circle are cast in the same piece with these vertical cheeks.

The vertical circle carrying the telescope is 3 feet in diameter, and, like the azimuth circle, is made of hard gun-metal. The aperture of the object-glass is 3¾ in. The top and bottom of the instrument each carries two levels, parallel to the plane of the vertical circle.

The dome over the instrument is cylindrical, with double sides, between which the air passes freely. Its diameter is 10 feet.

The drawing represents the instrument as in use. The ladder revolves in azimuth, with the instrument, round the central pier, —to facilitate which motion, rollers are placed under it. Two boards are attached to the revolving frame, having their edges in a plane parallel to that of the vertical circle. The eye being directed along these to view the object, the instrument is placed very nearly in the proper azimuth, and the telescope is then accurately directed to the object by the ring-finder. These boards are omitted in the drawing.

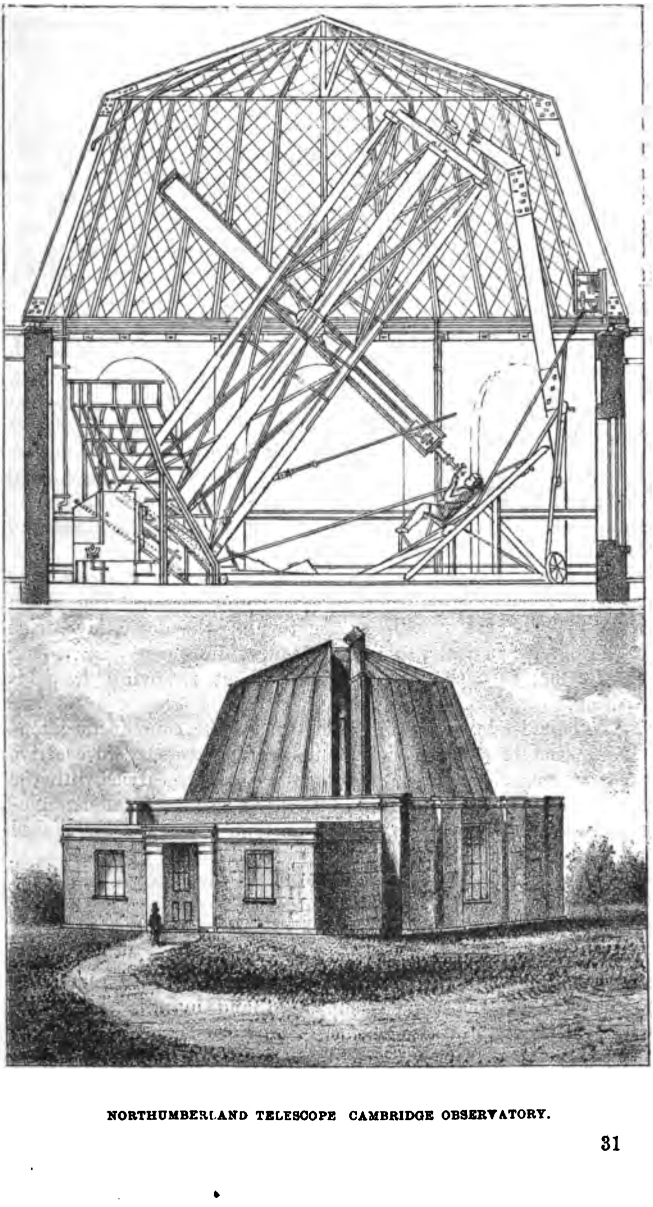
The results of the observations made with this instrument are stated to have fulfilled all the anticipations of the Astronomer Royal, as well as to the number of observations as to their excellence. At least twice the number have been made and of equal goodness with those formerly made with the meridional instruments. Some have been made even within a day of conjunction; and Mr. Main, the chief assistant at the Observatory, has expressed his conviction that in a few years observations with this instrument, will remove all the deficiencies which still remain in the lunar theory.

12. *The Northumberland telescope.—Cambridge Observatory.*—The late Duke of Northumberland, who filled during the latter part of his life the high and honourable office of Chancellor of the University of Cambridge, presented to that university this instrument, which, successively in the hands of the Astronomer Royal and Professor Challis, has contributed so effectually to the advancement of astronomical science.

The instrument, of which a perspective view is given in the annexed figure, together with a view of the building in which it is erected, consists of a refracting telescope of 19½ feet focal length and 11½ inches aperture equatorially mounted. The polar axis, as appears in the drawing, consists of a system of framing composed of six strong deal poles, attached at the ends to two hexagonal frames of cast-iron, the centres of which support the upper and lower pivots on which the telescope revolves. These poles at the middle are braced by transverse iron bands, and by a system of diagonal rods of deal abutting near the middle of the poles. These give stiffness to the entire framing of the polar axis, and maintain the hexagonal frames square to it. Efficient means are provided to give elasticity to the supports of the pivots and smoothness to the equatorial motion.

The tube of the telescope is made of well-seasoned deal, and attached to one side of it is a flat brass bar, 6 feet long, carrying a small graduated arc at right angles to it at one end, and turning at the other on a pin fixed in the telescope tube at a distance of 30 inches from the axis of revolution. This arc, which is called the declination sector, serves to measure small differences of declination, and is read by a micrometer microscope fixed to the telescope tube.

NORTHUMBERLAND TELESCOPE.



NORTHUMBERLAND TELESCOPE CAMBRIDGE OBSERVATORY.

The hour circle, which measures the equatorial motion, is 5½ feet diameter, and is so arranged that it can be clamped to the telescope, or disengaged from it, at pleasure. It has two indexes with verniers, one fixed to the support of the lower pivot, and the other to the hexagonal frame. By setting the latter to a certain angle, determined by an observation of a star of known right ascension, the telescope can be directed to any proposed right ascension by means of the other index. Observations of right ascension can be made to one second of time. The outer rim of the circle is cut into teeth, which are acted on by an endless screw connected at pleasure by a brass rod with a large clock, by which a motion can be given to the telescope corresponding with the diurnal motion of the heavens.

The hour circle is clamped to the frame of the axis by a tangent screw clamp fixed to the frame itself, by means of which, with the aid of a handle extending to the place of the observer, he can, when the endless screw is applied, give motion to the instrument through a limited space upon the hour circle. The rate of motion given to the hour circle by the clock is not affected by this movement. The hour circle, therefore, going according to sidereal time, small differences of right ascension can be measured by reading off the angles pointed to by the movable index before and after the changes of position.

The dome which covers the instrument is supported so as to revolve on free balls between concave channels. The winch which acts on the machinery for turning the dome, is carried to the observer's chair, so that he can, while engaged in a long observation, turn the dome slowly without removing from his position.

The magnitude of the instrument, and the consequent extensive motion of the eye-piece, rendered it necessary to contrive adequate means by which the observer could be carried with the eye-piece by a common motion without any personal derangement which might disturb the observation. This is accomplished by means of an ingenious apparatus consisting of a frame, of which the upper edge is nearly a circular arc whose centre is the centre of the telescope, which frame traverses horizontally round a pin in the floor exactly below the centre of the telescope, the observer's chair sliding on the frame. The observer can, by means of a winch placed beside his chair, turn round the frame on which the chair is supported, and by means of a lever and ratchet wheel he can raise and lower the chair on the frame. He has also means of raising and depressing the back of the chair so as to give it the inclination he may at the moment find most convenient.

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